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THE EARTH AND SUN AS MAGNETS[1]

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IN 1891, Professor Arthur Schuster, speaking before the Royal Institution, asked a question which has been widely debated in recent years: "Is every large rotating body a magnet?" Since the days of Gilbert, who first recognized that the earth is a great magnet, many theories have been advanced to account for its magnetic properties. Biot, in 1805, ascribed them to a relatively short magnet near its center. Gauss, after an extended mathematical investigation, substituted a large number of small magnets, distributed in an irregular manner, for the single magnet of Biot. Grover suggested that terrestrial magnetism may be caused by electric currents, circulating around the earth and generated by the solar radiation. Soon after Rowland's demonstration in 1876 that a rotating electrically charged body produces a magnetic field, Ayrton and Perry attempted to apply this principle to the case of the earth. Rowland at once pointed out a mistake in their calculation, and showed that the high potential electric charge demanded by their theory could not possibly exist on the earth's surface. It remained for Schuster to suggest that a body made up of molecules which are neutral in the ordinary electrical or magnetic sense may nevertheless develop magnetic properties when rotated.

We shall soon have occasion to examine the two hypotheses advanced in support of this view. While both are promising, it can not be said that either has been sufficiently developed to explain completely the principal phenomena of terrestrial magnetism. If we turn to experiment, we find that iron globes, spun at great velocity in the laboratory, fail to exhibit magnetic properties. But this can be accounted for on either hypothesis. What we need is a globe of great size, which

[1] Address delivered upon the occasion of the semi-centennial anniversary of the foundation of the National Academy of Sciences, April 22, 1913.

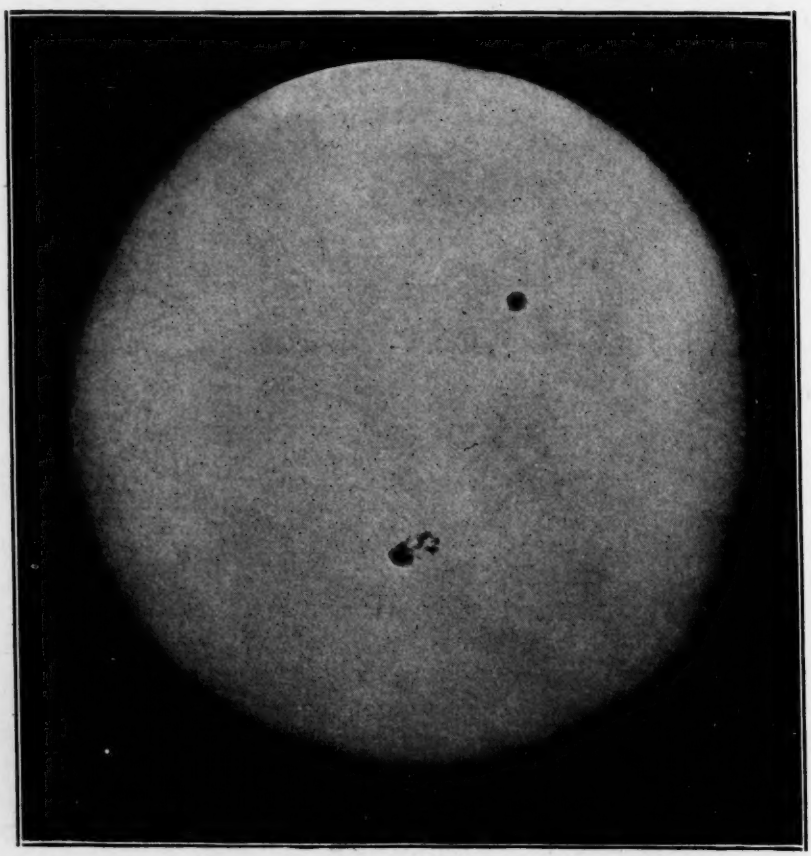

FIG 1. DIRECT PHOTOGRAPH OF THE SUN WITH DOT REPRESENTING EARTH FOR COMPARISON.

has been rotating for centuries at high velocity. The sun, with a diameter one hundred times that of the earth (Fig.1), may throw some light on the problem. Its high temperature wholly precludes the existence of permanent magnets: hence any magnetism it may exhibit must be due to motion. Its great mass and rapid linear velocity of rotation should produce a magnetic field much stronger than that of the earth. Finally, the presence in its atmosphere of glowing gases, and the well-known effect of magnetism on light, should enable us to explore its magnetic field even at the distance of the earth. The effects of ionization, probably small in the region of high pressure beneath the photosphere and marked in the solar atmosphere, must be determined and allowed for. But with this important limitation, the sun may be used by the physicist for an experiment which can not be performed in the best equipped laboratory.

Schuster, in the lecture already cited, remarked:

> The form of the corona suggests a further hypothesis which, extravagant

as it may appear at present, may yet prove to be true. Is the sun a magnet?

Summing up the situation in April, 1912, he repeated:

The evidence (whether the sun is a magnet) rests entirely on the form of certain rays of the corona, which—assuming that they indicate the path of projecting particles—seem to be deflected as they would be in a magnetic field, but this evidence is not at all decisive.

There remained the possibility of an appeal to a conclusive test of magnetism: the characteristic changes it produces in light which originates in a magnetic field.

Before describing how this test has been applied, let us rapidly recapitulate some of the principal facts of terrestrial magnetism. You see upon the screen the image of a steel sphere (Fig. 2), which has been

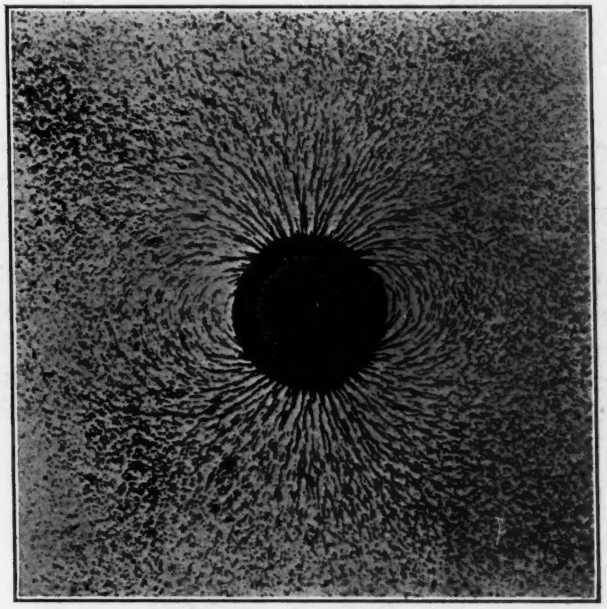

FIG. 2. LINES OF FORCE OF A MAGNETIZED STEEL SPHERE.

strongly magnetized. If iron filings are sprinkled over the glass plate that supports it, each minute particle becomes a magnet under the influence of the sphere. When the plate is tapped, to relieve the friction, the particles fall into place along the lines of force, revealing a characteristic pattern of great beauty. A small compass needle, moved about the sphere, always turns so as to point along the lines of force. At the magnetic poles, it points toward the center of the sphere. Midway between them, at the equator, it is parallel to the diameter joining the poles.

As the earth is a magnet, it should exhibit lines of force resembling those of the sphere. If the magnetic poles coincided with the poles of rotation, a freely suspended magnetic needle should point vertically

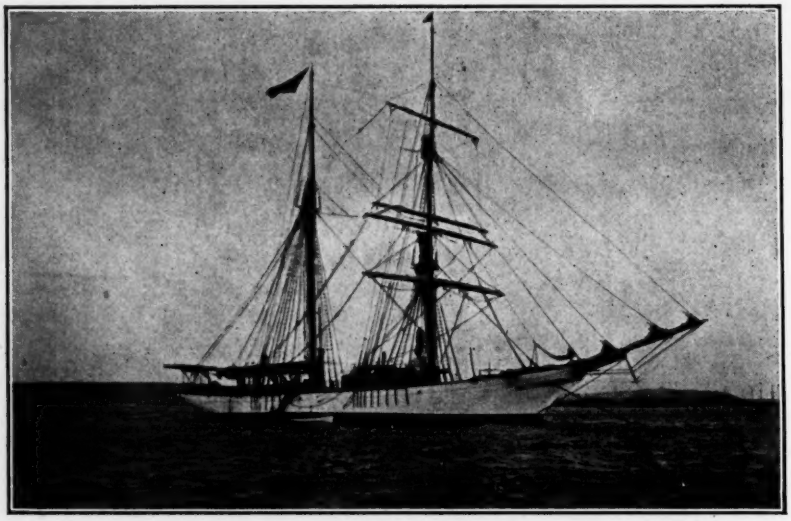

FIG. 3. THE NON-MAGNETIC YACHT *Carnegie*.

downward at one pole, vertically upward at the other, and horizontally at the equator. A dip needle, used to map the lines of force of the earth, is shown on the screen. I have chosen for illustration an instrument designed for use at sea, on the non-magnetic yacht *Carnegie* (Fig. 3), partly because the equipment used by Dr. Bauer in his extensive surveys represents the best now in use, and also because I wish to contrast the widely different means employed by the Carnegie Institution for the investigation of solar and terrestrial magnetic phenomena. The support of the dip-needle is hung in gimbals, so that observations may be taken when the ship's deck is inclined. The smallest possible amount of metal enters into the construction of this vessel, and where its use could not be avoided, bronze was employed instead of iron or steel. She is thus admirably adapted for magnetic work, as is shown by the observations secured on voyages already totaling more than 100,000 miles. Her work is supplemented by that of land parties, bearing instruments to remote regions where magnetic observations have never before been made.

The dip-needle clearly shows that the earth is a magnet, for it behaves in nearly the same way as the little needle used in our experiment with the magnetized sphere. But the magnetic poles of the earth do not coincide with the geographical poles. The north magnetic pole, discovered by Ross and last visited by Amundsen in 1903, lies near Baffin's Bay, in latitude 70° north, longitude 97° west. The position of the south magnetic pole, calculated from observations made in its vicinity by Captain Scott, of glorious memory, in his expedition of 1901–04, is 72° 50′ south latitude, 153° 45′ east longitude. Thus the two magnetic poles are not only displaced about 30° from the geograph-

ical poles: they do not even lie on the same diameter of the earth. Moreover, they are not fixed in position, but appear to be rotating about the geographical poles in a period of about 900 years. In addition to these peculiarities, it must be added that the dip-needle shows the existence of local magnetic poles, one of which has recently been found by Dr. Bauer's party at Treadwell Point, Alaska. At such a place the direction of the needle undergoes rapid change as it is moved about the local pole.

The dip-needle, as we have seen, is free to move in a vertical plane. The compass needle moves in a horizontal plane. In general, it tends to point toward the magnetic pole, and as this does not correspond with the geographical pole, there are not many places on the earth's surface where the needle indicates true north and south. Local peculiarities, such as deposits of iron ore, also affect its direction very materially. Thus a variation chart, which indicates the deviation of the compass needle from geographical north, affords an excellent illustration of the irregularities of terrestrial magnetism. The necessity for frequent and accurate surveys of the earth's magnetic field is illustrated by the fact that the *Carnegie* has found errors of five or six degrees in the variation charts of the Pacific and Indian oceans.

In view of the earth's heterogeneous structure, which is sufficiently illustrated by its topographical features, marked deviations from the uniform magnetic properties of a magnetized steel sphere are not at all surprising. The phenomenon of the secular variation, or the rotation of the magnetic poles about the geographical poles, is one of the peculiarities toward the solution of which both theory and experiment should be directed.

Passing over other remarkable phenomena of terrestrial magnetism,

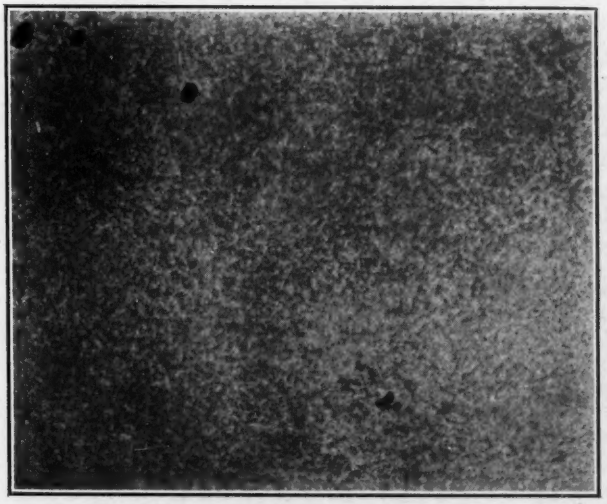

FIG. 4. DIRECT PHOTOGRAPH OF PART OF THE SUN, APRIL 30, 1908.

we come to magnetic storms and auroras, which are almost certainly of solar origin.

Here is a photograph of the sun, as it appears in the telescope (Fig. 4).[2] Scattered over its surface are sun-spots, which increase and decrease in number in a period of about 11.3 years. It is well known that a curve, showing the number of spots on the sun, is closely similar to a curve representing the variations of intensity of the earth's magnetism. The time of maximum sun-spots corresponds with that of reduced intensity of the earth's magnetism, and the parallelism of the two curves is too close to be the result of accident. We may therefore conclude that there is some connection between the spotted area of the sun and the magnetic field of the earth.

We shall consider a little later the nature of sun-spots, but for the present we may regard them simply as solar storms. When spots are numerous the entire sun is disturbed, and eruptive phenomena, far transcending our most violent volcanic outbursts, are frequently visible. In the atmosphere of the sun, gaseous prominences rise to great heights. This one, reaching an elevation of 85,000 miles, is of the quiescent type, which changes gradually in form and is abundantly found at all phases of the sun's activity. But such eruptions as the one of March 25, 1895, photographed with the spectroheliograph of the Kenwood Observatory, are clearly of an explosive nature. As these photographs show, it shot upward through a distance of 146,000 miles in 24 minutes, after which it faded away.

When great and rapidly changing spots, usually accompanied by eruptive prominences, are observed on the sun, brilliant displays of the aurora (Fig. 5) and violent magnetic storms are often reported. The magnetic needle, which would record a smooth straight line on the photographic film if it were at rest, trembles and vibrates, drawing a broken and irregular curve. Simultaneously, the aurora flashes and pulsates, sometimes lighting up the northern sky with the most brilliant display of red and green discharges.

Birkeland and Störmer have worked out a theory which accounts in a very satisfactory way for these phenomena. They suppose that electrified particles, shot out from the sun with great velocity, are drawn in toward the earth's magnetic poles along the lines of force. Striking the rarified gases of the upper atmosphere, they illuminate them, just as the electric discharge lights up a vacuum tube. There is reason to believe that the highest part of the earth's atmosphere consists of rarified hydrogen, while nitrogen predominates at a lower level. Some of the electrons from the sun are absorbed in the hydrogen, above a height of 60 miles. Others reach the lower-lying nitrogen, and descend to levels from 30 to 40 miles above the earth's surface. Certain still

[2] Figs. 4, 6 and 7 represent the same region of the sun, photographed at successively higher levels.

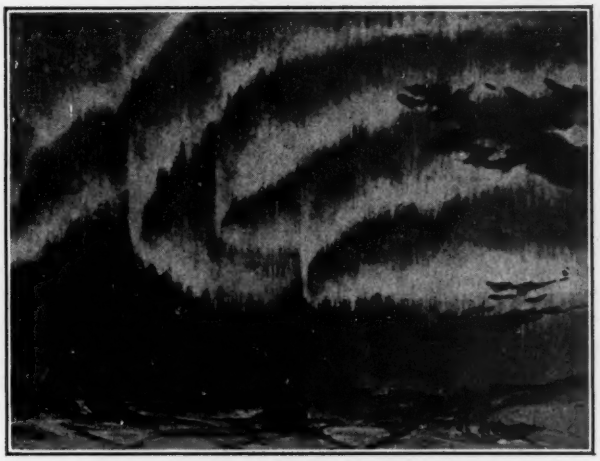

FIG. 5. THE AURORA.

more penetrating rays sometimes reach an altitude of 25 miles, the lowest hitherto found for the aurora. The passage through the atmosphere of the electrons which cause the aurora also gives rise to the irregular disturbances of the magnetic needle observed during magnetic storms.

The outflow of electrons from the sun never ceases, if we may reason from the fact that the night sky is at all times feebly illuminated by the characteristic light of the aurora. But when sun-spots are numerous, the discharge of electrons is most violent, thus explaining the frequency of brilliant auroras and intense magnetic storms during sun-spot maxima. It should be remarked that the discharge of electrons does not necessarily occur from the spots themselves, but rather from the eruptive regions surrounding them.

Our acquaintance with vacuum tube discharges dates from an early period, but accurate knowledge of these phenomena may be said to begin with the work of Sir William Crookes in 1876. A glass tube, fitted with electrodes, and filled with any gas, is exhausted with a suitable pump until the pressure within it is very low. When a high voltage discharge is passed through the tube, a stream of negatively-charged particles is shot out from the cathode, or negative pole, with great velocity. These electrons, bombarding the molecules of the gas within the tube, produce a brilliant illumination, the character of which depends upon the nature of the gas. The rare hydrogen gas in the upper atmosphere of the earth, when bombarded by electrons from the sun, glows like the hydrogen in this tube. Nitrogen, which is characteristic of a lower level, shines with the light which can be duplicated here.

But it may be remarked that this explanation of the aurora is only hypothetical, in the absence of direct evidence of the emission of electrons by the sun. However, we do know that hot bodies emit electrons.

Here is a carbon filament in an exhausted bulb. When heated white hot, a stream of electrons passes off. Falling upon this electrode, the electrons discharge the electroscope with which it is connected. Every one who has to discard old incandescent lamps is familiar with the result of this outflow. The blackening of the bulbs is due to finely divided carbon carried away by the electrons, and deposited upon the glass.

Now we know that great quantities of carbon in a vaporous state exist in the sun, and that many other substances, also present there, emit electrons in the same way. Hence we may infer that electrons are abundant in the solar atmosphere.

The temperature of the sun is between 6,000° and 7,000° C., twice as high as we can obtain by artificial means. Under solar conditions, the velocity of the electrons emitted in regions where the pressure is not too great may be sufficient to carry them to the earth. Arrhenius holds that the electrons attach themselves to molecules or groups of molecules, and are then driven to the earth by light-pressure.

In certain regions of the sun, we have strong evidence of the existence of free electrons. This leads us to the question of solar magnetism and suggests a comparison of the very different conditions in the sun and earth. Much alike in chemical composition, these bodies differ principally in size, in density and in temperature. The diameter of the sun is more than one hundred times that of the earth, while its density is only one quarter as great. But the most striking point of difference is the high temperature of the sun, which is much more than sufficient to vaporize all known substances. This means that no permanent magnetism, such as is exhibited by a steel magnet or a lodestone, can exist in the sun. For if we bring this steel magnet to a red heat, it loses its magnetism, and drops the iron bar which it previously supported. Hence, while some theories attribute terrestrial magnetism to the presence within the earth of permanent magnets, no such theory can apply to the sun. If magnetic phenomena are to be found there, they must result from other causes.

The familiar case of the helix illustrates how a magnetic field is produced by an electric current flowing through a coil of wire. But according to the modern theory, an electric current is a stream of electrons. Thus a stream of electrons in the sun should give rise to a magnetic field. If the electrons were whirled in a powerful vortex, resembling our tornadoes or water-spouts, the analogy with the wire helix would be exact, and the magnetic field might be sufficiently intense to be detected by spectroscopic observations.

A sun-spot, as seen with a telescope or photographed in the ordinary way, does not appear to be a vortex. If we examine the solar atmosphere above and about the spots, we find extensive clouds of luminous calcium vapor, invisible to the eye, but easily photographed with the

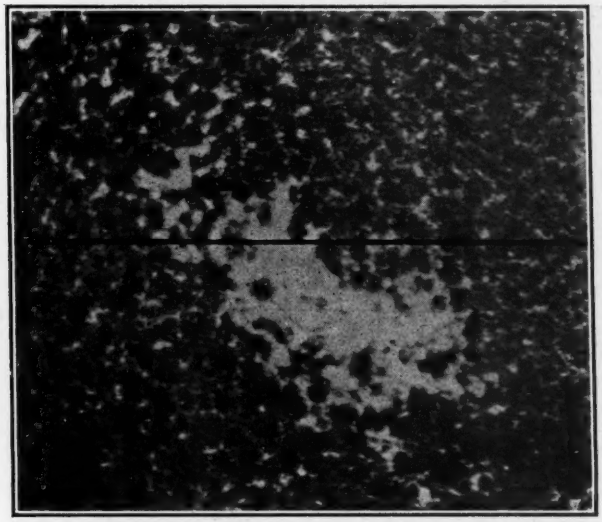

FIG. 6. CALCIUM (H_2) FLOCCULI PHOTOGRAPHED WITH THE SPECTROHELIOGRAPH, APRIL 30, 1908.

spectroheliograph, by admitting no light to the sensitive plate except that radiated by calcium vapor. These calcium flocculi (Fig. 6), like the cumulus clouds of the earth's atmosphere, exhibit no well-defined linear structure. But if we photograph the sun with the red light of hydrogen, we find a very different condition of affairs (Fig. 7). In this higher region of the solar atmosphere, first photographed on Mount Wilson in 1908, cyclonic whirls, centering in sun-spots, are clearly shown.

The idea that sun-spots may be solar tornadoes, which was strongly

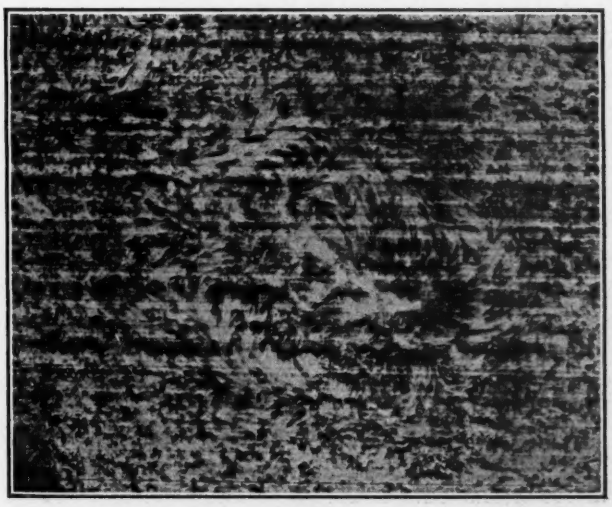

FIG. 7. HYDROGEN ($H\alpha$) FLOCCULI PHOTOGRAPHED WITH THE SPECTROHELIOGRAPH, APRIL 30, 1908.

suggested by such photographs, soon received striking confirmation. A great cloud of hydrogen, which had hung for several days on the edge of one of these vortex structures, was suddenly swept into the spot at a velocity of about 60 miles per second. More recently Slocum has photographed at the Yerkes Observatory a prominence at the edge of the sun, flowing into a spot with a somewhat lower velocity.

Thus we were led to the hypothesis that sun-spots are closely analogous to tornadoes or water-spouts in the earth's atmosphere (Fig. 8).

FIG. 8. WATER-SPOUT.

If this were true, electrons, caught and whirled in the spot vortex, should produce a magnetic field. Fortunately, this could be put to a conclusive test, through the well-known influence of magnetism on light discovered by Zeeman in 1896.

In Zeeman's experiment a flame containing sodium vapor was placed between the poles of a powerful electro-magnet. The two yellow sodium lines, observed with a spectroscope of high dispersion, were seen to widen the instant a magnetic field was produced by passing a current through the coils of the magnet. It was subsequently found that most of the lines of the spectrum, which are single under ordinary conditions, are split into three components when the radiating source is in a sufficiently intense magnetic field. This is the case when the observation is made at right angles to the lines of force. When looking along the lines of force, the central line of such a triplet disappears (Fig. 9), and the light of the two side components is found to be circularly polarized in oppo-

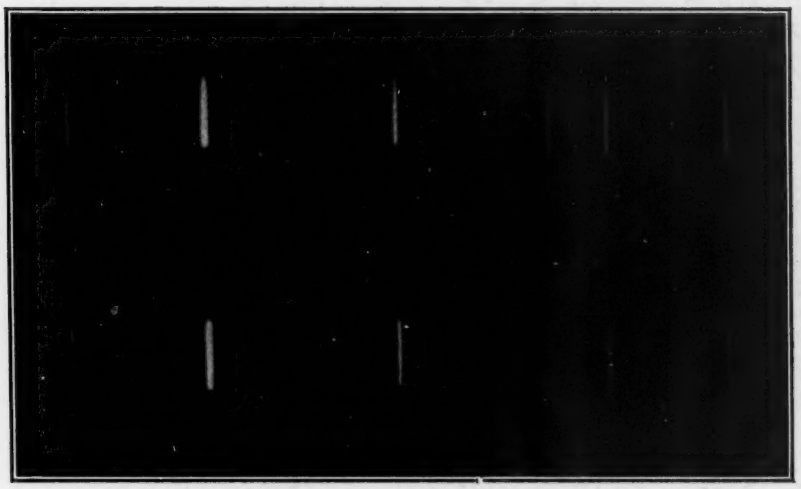

FIG. 9. ZEEMAN DOUBLET PHOTOGRAPHED IN LABORATORY SPECTRUM. The middle section shows the doublet. The adjacent sections indicate the appearance of the spectrum line in the absence of a magnetic field.

site directions. With suitable polarizing apparatus, either component of such a line can be cut off at will, leaving the other unchanged. Furthermore, a double line having these characteristic properties can be produced only by a magnetic field. Thus it becomes a simple matter to detect a magnetic field, at any distance, by observing its effect on light emitted within the field. If a sun-spot is an electric vortex, and the observer is supposed to look along the axis of the whirling vapor, which would correspond with the direction of the lines of force, he should find the spectrum lines double, and be able to cut off either component with the polarizing attachment of his spectroscope.

I applied this test to sun-spots on Mount Wilson in June, 1908, with the 60-foot tower telescope, and at once found all of the characteristic features of the Zeeman effect. Most of the lines of the sun-spot spectrum are merely widened by the magnetic field, but others are split into separate components (Fig. 10), which can be cut off at will by the observer. Moreover, the opportune formation of two large spots, which appeared on the spectroheliograph plates to be rotating in opposite directions (Fig. 11), permitted a still more exacting experiment to be tried. In the laboratory, where the polarizing apparatus is so adjusted as to transmit one component of a line doubled by a magnetic field, this disappears and is replaced by the other component when the direction of the current is reversed. In other words, one component is visible alone when the observer looks toward the north pole of the magnet, while the other appears alone when he looks toward the south pole. If electrons of the same kind are rotating in opposite directions in two sun-spot vortices, the observer should be looking toward a north pole in one spot and toward a south pole in the other. Hence the

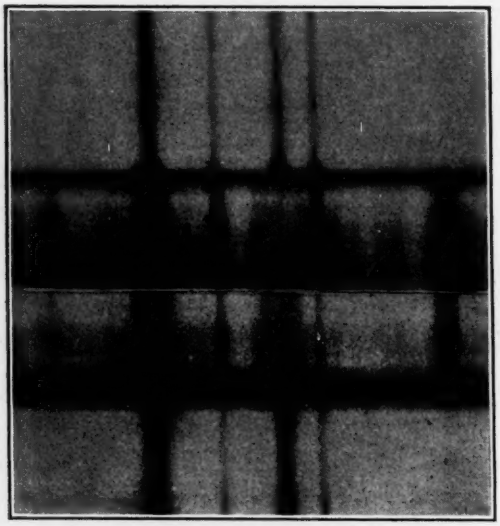

FIG. 10. *a*, *b*, spectra of two sun-spots. The triple line indicates a magnetic field of 4,500 gausses in *a*, and one of 2,900 gausses in *b*.

opposite components of a magnetic double line should appear in two such spots. As our photographs show, the result of the test was in harmony with my anticipation.

I may not pause to describe the later developments of this investigation, though two or three points must be mentioned. The intensity of the magnetic field in sun-spots is sometimes as high as 4,500 gausses, or nine thousand times the intensity of the earth's field. In passing upward from the sun's surface, the magnetic intensity decreases very

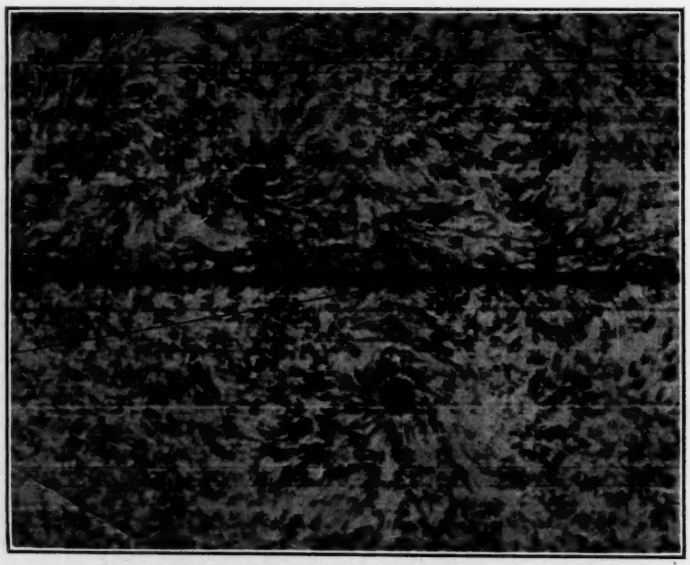

FIG. 11. RIGHT- AND LEFT-HANDED VORTICES SURROUNDING SUN-SPOTS indicated by the distribution of hydrogen ($H\alpha$) gas. Photographed with the spectroheliograph.

rapidly—so rapidly, in fact, as to suggest the existence of an opposing field. It is probable that the vortex which produces the observed field is not the one that appears on our photograph, but lies at a lower level. In fact, the vortex structure shown on spectroheliograph plates may represent the effect, rather than the cause of the sun-spot field. We may have, as Brester and Deslandres suggest, a condition analogous to that illustrated in the aurora: electrons, falling in the solar atmosphere, move along the lines of force of the magnetic field into spots. In this way we may perhaps account for the structure surrounding pairs of spots, of opposite polarity, which constitute the typical sun-spot group. The resemblance of the structure near these two bipolar groups to the lines of force about a bar magnet is very striking, especially when the disturbed condition of the solar atmosphere, which tends to mask the effect, is borne in mind. It is not unlikely that the bipolar group is due to a single vortex, of the horse-shoe type, such as we may see in water after every sweep of an oar.

We thus have abundant evidence of the existence on the sun of local magnetic fields of great intensity—fields so extensive that the earth is small in comparison with many of them. But how may we account for the copious supply of electrons needed to generate the powerful currents required in such enormous electro-magnets? Neutral molecules, postulated in theories of the earth's field, will not suffice. A marked preponderance of electrons of one sign is clearly indicated.

An interesting experiment, due to Harker, will help us here. Imagine a pair of carbon rods, insulated within a furnace heated to a temperature of two or three thousand degrees. The outer ends of the rods, projecting from the furnace, are connected to a galvanometer. Harker found that when one of the carbon terminals within the furnace was cooler than the other, a stream of negative electrons flowed toward it from the hotter electrode. Even at atmospheric pressure, currents of several amperes were produced in this way.[3]

Our spectroscopic investigations, interpreted by laboratory experiments, are in harmony with those of Fowler in proving that sun-spots are comparatively cool regions in the solar atmosphere. They are hot enough, it is true, to volatilize such refractory elements as titanium, but cool enough to permit the formation of certain compounds not found elsewhere in the sun. Hence, from Harker's experiment, we may expect a flow of negative electrons toward spots. These, caught and whirled in the vortex, would easily account for the observed magnetic fields.

The conditions existing in sun-spots are thus without any close parallel among the natural phenomena of the earth. The sun-spot vortex is not unlike a terrestrial tornado, on a vast scale, but if the

[3] King has recently found that the current decreases very rapidly as the pressure increases, but is still appreciable at a pressure of 20 atmospheres.

whirl of ions in a tornado produces a magnetic field, it is too feeble to be readily detected. Thus, while we have demonstrated the existence of solar magnetism, it is confined to limited areas. We must look further if we would throw new light on the theory of the magnetic properties of rotating bodies.

This leads us to the question with which we started: is the sun a magnet like the earth? The structure of the corona, as revealed at total eclipses, points strongly in this direction. Remembering the lines of force of our magnetized steel sphere, we can not fail to be struck by their close resemblance to the polar streamers in these beautiful photographs of the corona (Fig. 12) taken by Lick Observatory eclipse parties, for which

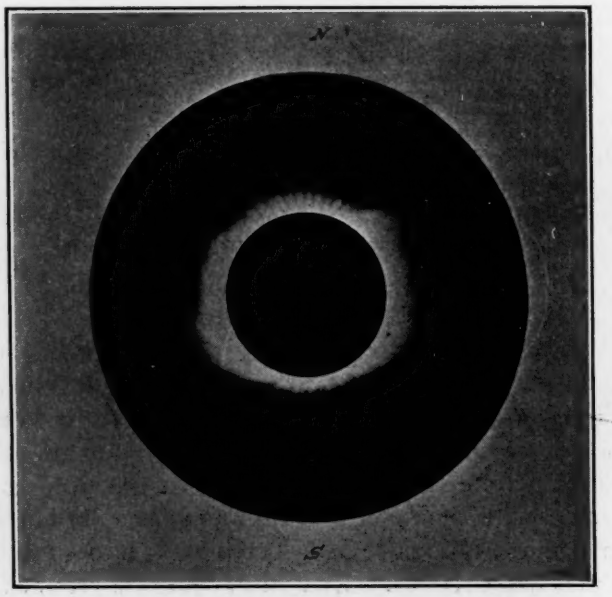

FIG. 12. SOLAR CORONA, SHOWING POLAR STREAMERS.

I am indebted to Professor Campbell. Bigelow, in 1889, investigated this coronal structure, and showed that it is very similar to the lines of force of a spherical magnet. Störmer, guided by his own researches on the aurora, has calculated the trajectories of electrons moving out from the sun under the influence of a general magnetic field, and compared these trajectories with the coronal streamers. The resemblance is apparently too close to be the result of chance. Finally, Deslandres has investigated the forms and motions of solar prominences, which he finds to behave as they would in a magnetic field of intensity about one millionth that of the earth. We may thus infer the existence of a general solar magnetic field. But since the sign of the charge of the outflowing electrons is not certainly known, we can not determine the polarity of the sun in this way. Furthermore, our present uncertainty

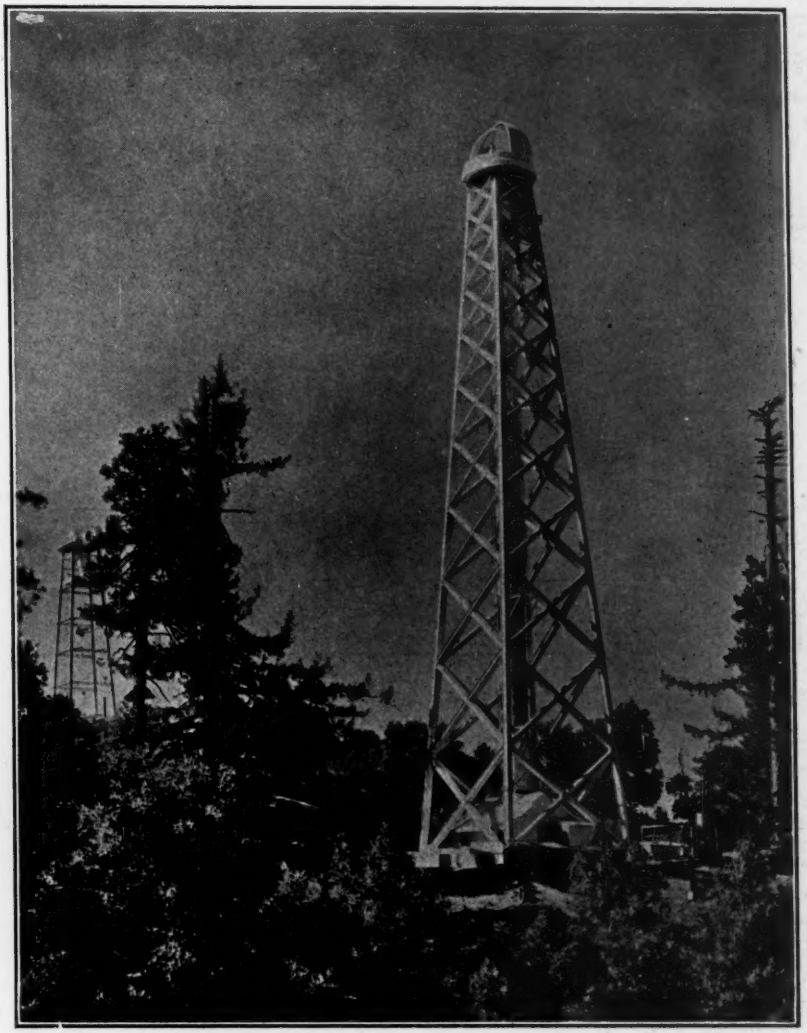

FIG. 13. 150-FOOT TOWER TELESCOPE.

as to the proportion at different levels of positive and negative electrons, and of the perturbations due to currents in the solar atmosphere, must delay the most effective application of these methods, though they promise much future knowledge of the magnetic field at high levels in the solar atmosphere.

Of the field at low levels, however, they may tell us little or nothing, for the distribution of the electrons may easily be such as to give rise to a field caused by the rotation of the solar atmosphere, which may oppose in sign the field due to the rotation of the body of the sun. To detect this latter field, the magnetic field of the sun as distinguished from that of the sun's atmosphere, we must resort to the method employed in the case of sun-spots—the study of the Zeeman effect. If

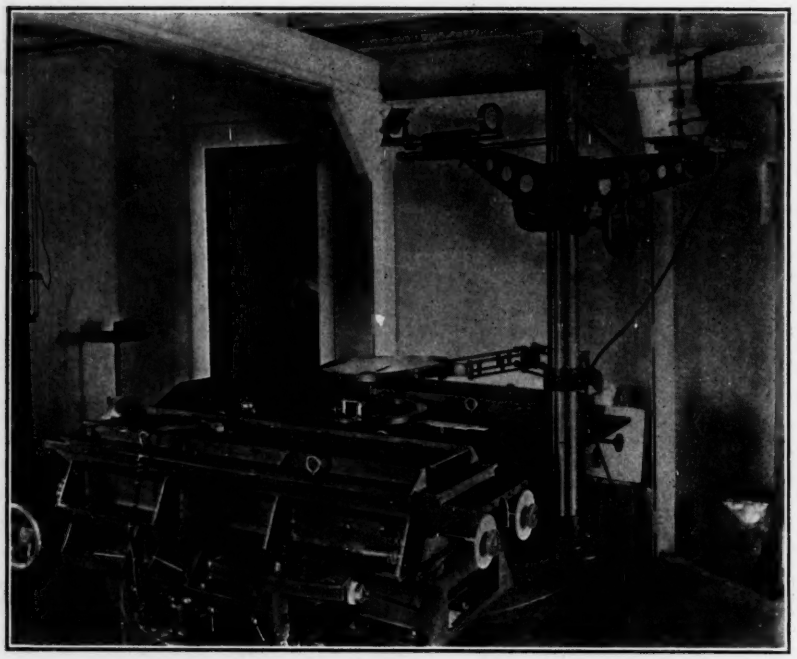

FIG. 14. HEAD OF THE 75-FOOT SPECTROGRAPH OF THE 150-FOOT TOWER TELESCOPE.

this is successful, it will not only show beyond doubt whether the sun is a magnet: it will also permit the polarity of the sun to be compared with that of the earth, give a measure of the strength of the field at different latitudes, and indicate the sign of the charge that a rotating sphere must possess if it is to produce a similar field.

I first endeavored to apply this test with the 60-foot tower telescope in 1908, but the results were too uncertain to command confidence.

Thanks to additional appropriations from the Carnegie Institution of Washington, a new and powerful instrument was available on Mount Wilson for a continuation of the investigation in January, 1912. The new tower telescope has a focal length of 150 feet (Fig. 13). To prevent vibration in the wind, the cœlostat, second mirror and object-glass are carried by a skeleton tower, each vertical and diagonal member of which is enclosed within the corresponding member of an outer skeleton tower, which also carries a dome to shield the instruments from the weather. In the photograph, we see only the hollow members of the outer tower. But within each of them, well separated from possible contact, a sectional view would show the similar, but more slender members of the tower that supports the instruments. The plan has proved to be successful, permitting observations demanding the greatest steadiness of the solar image to be made.

The arrangements are similar to those of the 60-foot tower. The solar image, 16½ inches in diameter, falls on the slit of a spectrograph

(Fig. 14) in the observation house at the ground level. The spectrograph, of 75 feet focal length, enjoys the advantage of great stability and constancy of temperature in its subterranean vault beneath the tower. In the third order spectrum, used for this investigation, the D lines of the solar spectrum are 29 millimeters apart. The resolving power of the excellent Michelson grating is sufficient to show 75 lines of the iodine absorption spectrum in this space between the D's. Thus the instruments are well suited for the exacting requirements of a difficult investigation. For it must be borne in mind that the problem is very different from that of detecting the magnetic fields in sun-spots, where the separation of the lines is from fifty to one hundred times as great as we may expect to find here. Thus the sun's general field can produce no actual separation of the lines. But it may cause a very slight widening, which should appear as a displacement when suitable polarizing apparatus is used. This is so arranged as to divide the spectrum longitudinally into narrow strips. The component toward the red end of the spectrum of a line widened by magnetism should appear in one strip, the other component in the next strip. Hence, if the sun has a magnetic field of sufficient strength, the line should have a dentated appearance. The small relative displacements of the lines on successive strips, when measured under a microscope, should give the strength of the magnetic field.

The above remarks apply strictly to the case when the observer is looking directly along the lines of force. At other angles neither component is completely cut off, and the magnitude of the displacement will then depend upon two things: the strength of the magnetic field and the angle between the line of sight and the lines of force. Assuming that the lines of force of the sun correspond with those of a magnetized sphere, and also that the magnetic poles coincide with the poles of rotation, it is possible to calculate what the relative displacement should be at different solar latitudes. These theoretical displacements are shown graphically by the sine curve on the screen (Fig. 15).

We see from the curve that the greatest displacements should be found at 45° north and south latitude, and that from these points they should decrease toward zero at the equator and the poles. Furthermore, the curve shows that we may apply the same crucial test used in the case of sun-spots: the direction of the displacements, toward red or violet, should be reversed in the northern and southern hemispheres.

I shall not trouble you with the details of the hundreds of photographs and the thousands of measures which have been made by my colleagues and myself during the past year. In view of the diffuse character of the solar lines under such high dispersion, and the exceedingly small displacements observed, the results must be given with some reserve, though they appear to leave no doubt as to the reality of the effect. Observations in the second order spectrum failed to give

satisfactory indications of the field. But with the higher dispersion of the third order eleven independent determinations, made with every possible precaution to eliminate bias, show opposite displacements in

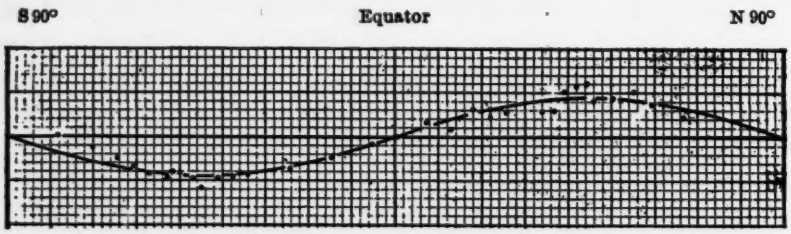

FIG. 15. The curve represents the theoretical variation of the displacements of spectrum lines with the heliographic latitude. The sun is assumed to be a magnetized sphere with its magnetic poles coinciding with the poles of rotation. The points represent mean values of the observed displacements. Vertical scale: 1 square = 0.001 mm. = 0.0002 Angström.

the northern and southern hemispheres, decreasing in magnitude from about 45° north and south latitude to the equator. Three of these determinations were pushed as close to the poles as conditions would permit, and the observed displacements may be compared with the theoretical curve (Fig. 15). In view of the very small magnitude of the displacements, which never surpass 0.002 Angströms, the agreement is quite as satisfactory as one could expect for a first approximation.

The full details of the investigation are given in a paper recently published.[4] The reader will find an account of the precautions taken to eliminate error, and, I trust, no tendency to underestimate the possible adverse bearing of certain negative results. It must remain for the future to confirm or to overthrow the apparently strong evidence in favor of the existence of a true Zeeman effect, due to the general magnetic field of the sun. If this evidence can be accepted, we may draw certain conclusions of present interest.

Taking the measures at their face value, they indicate that the north magnetic pole of the sun lies at or near the north pole of rotation, while the south magnetic pole lies at or near the south pole of rotation. In other words, if a compass needle could withstand the solar temperature, it would point approximately as it does on the earth, since the polarity of the two bodies appears to be the same. Thus, since the earth and sun rotate in the same direction, a negative charge distributed through their mass would account in each case for the observed magnetic polarity.

As for the strength of the sun's field, only three preliminary determinations have yet been made, with as many different lines. Disregarding the systematic error of measurement, which is still very uncertain, these indicate that the field-strength at the sun's poles is of the order of 50 gausses (about eighty times that of the earth).

[4] *Contributions from the Mount Wilson Solar Observatory*, No. 71.

Schuster, assuming the magnetic fields of the earth and sun to be due to their rotation, found that the strength of the sun's field should be 440 times that of the earth, or 264 gausses. This was on the supposition that the field-strength of a rotating body is proportional to the product of the radius and the maximum linear velocity of rotation, but neglected the density. Before inquiring why the observed and theoretical values differ, we may glance at the two most promising hypotheses that have been advanced in support of the view that every large rotating body is a magnet.

On account of their greater mass, the positive electrons of the neutral molecules within the earth may perhaps be more powerfully attracted by gravitation than the negative electrons. In this case the negative charge of each molecule should be a little farther from the center of the earth than the positive charge. The average linear velocity of the negative charge would thus be a little greater, and the magnetizing effect due to its motion would slightly exceed that due to the motion of the positive charge. By assuming a separation of the charges equal to about four tenths the radius of a molecule (Bauer), the symmetrical part of the earth's magnetic field could be accounted for as the result of the axial rotation.

This theory, first suggested by Thomson, has been developed by Sutherland, Schuster and Bauer. But as yet it has yielded no explanation of the secular variation of the earth's magnetism, and other important objections have been urged against it. While it should not be rejected, the merits of other theories must not be overlooked.

Chief among these is the theory that rests on the very probable assumption that every molecule is a magnet. If the magnetism is accounted for as the effect of the rapid revolution of electrons within the molecule, a gyrostatic action might be anticipated. That is, each molecule would tend to set itself with its axis parallel to the axis of the earth, just as the gyrostatic compass, now coming into use at sea, tends to point to the geographical pole. The host of molecular magnets, all acting together, might account for the earth's magnetic field.

This theory, in its turn, is not free from obvious points of weakness, though they may disappear as the result of more extended investigation. Its chief advantage lies in the possibility that it may explain the secular variation of the earth's magnetism by a precessional motion of the magnetic molecules.

On either hypothesis, it is assumed, in the absence of knowledge to the contrary, that every molecule contributes to the production of the magnetic field. Thus the density of the rotating body may prove to be a factor. Perhaps the change of density from the surface to the center of the sun must also be taken into account. But the observational results already obtained suggest that the phenomena of ionization in the solar atmosphere may turn out to be the predominant influence.

The lines which show the Zeeman effect originate at a comparatively low level in the solar atmosphere. Preliminary measures indicate that certain lines of titanium, which are widely separated by a magnetic field in the laboratory, are not appreciably affected in the sun. As these lines represent a somewhat higher level, it is probable that the strength of the sun's field decreases very rapidly in passing upward from the surface of the photosphere—a conclusion in harmony with results obtained from the study of the corona and prominences. Thus it may be found that the distribution of the electrons is such as to give rise to the observed field or to produce a field opposing that caused by the rotation of the body of the sun. It is evident that speculation along these lines may advantageously await the accumulation of observations covering a wide range of level. Beneath the photosphere, where the pressure is high, we may conclude from recent electric furnace experiments by King that free electrons, though relatively few, may nevertheless play some part in the production of the general magnetic field.

In this survey of magnetic phenomena, we have kept constantly in mind the hypothesis that the magnetism of the earth is due to its rotation. Permanent magnets, formerly supposed to account for the earth's magnetic field, could not exist at the high temperature of the sun. Displays of the aurora, usually accompanied by magnetic storms, are plausibly attributed to electrons reaching the earth from the sun, and illuminating the rare gases of the upper atmosphere just as they affect those in a vacuum tube. Definite proof of the existence of free electrons in the sun is afforded by the discovery of powerful local magnetic fields in sun-spots, where the magnetic intensity is sometimes as great as nine thousand times that of the earth's field. These local fields probably result from the rapid revolution in a vortex of negative electrons, flowing toward the cooler spot from the hotter region outside. The same method of observation now indicates that the whole sun is a magnet, of the same polarity as the earth. Because of the high solar temperature, this magnetism may be ascribed to the sun's axial rotation.[5] It is not improbable that the earth's magnetism also results from its rotation, and that other rotating celestial bodies, such as stars and nebulæ, may ultimately be found to possess magnetic properties. Thus, while the presence of free electrons in the sun prevents our acceptance of the evidence as a proof that every large rotating body is a magnet, the results of the investigation are not opposed to this hypothesis, which may be tested further by the study of other stars of known diameter and velocity of rotation.

[5] The alternative hypothesis, that the sun's magnetism is due to the combined effect of numberless local magnetic fields, caused by electric vortices in the solar "pores," though at first sight improbable, deserves further consideration.

EUGENICS: WITH SPECIAL REFERENCE TO INTELLECT AND CHARACTER[1]

BY PROFESSOR EDWARD L. THORNDIKE

TEACHERS COLLEGE, COLUMBIA UNIVERSITY

BY eugenics is meant, as you all know, the improvement of mankind by breeding. It has been decided by those responsible for this lecture—Mrs. Huntington Wilson and the president and trustees of the university—that its topic shall be the intellectual and moral, rather than the physical, improvement of the human stock.

Common observation teaches that individuals of the same sex and age differ widely in intellect, character and achievement. The more systematic and exact observations made by scientific students of human nature emphasize the extent of these differences. Whether we take some trivial function—such as memory for isolated words, or delicacy of discrimination of pitch—or take some broad symptom of man's nature, such as his rate of progress through school, or ability in tests of abstract intellect, or even his general intellectual and moral repute—men differ widely. Samples of the amount and distribution of such differences are given in Charts 1, 2 and 3. Chart 1 relates that of 732 children who had studied arithmetic equally long, one could get over a hundred examples done correctly in fifteen minutes, while others could not get correct answers to five. Even if we leave out of account the top three per cent., covering all the records of 60 or over, we have some children achieving twenty-five times as many correct answers as other children.

Chart 2 shows that when four hundred children who had had similar school training were given each the same amount of practise in certain work in division, some improve not at all, and others enormously. Chart 3 shows that of children in the same school all of the same year-age (thirteen), some have done the work of the eight grades of the elementary school and of one or two years of the high school, while others have not completed the work of a single year. Still less competence at intellectual tasks could be found by including children from asylums for imbeciles and idiots.

The differences thus found amongst individuals of the same sex and age are due in large measure to original, inborn characteristics of the intellectual and moral constitution of the individuals in question. They are, it is true, in part due to differences in maturity—one thirteen-year-old being further advanced in development than another. They are

[1] A lecture given at Columbia University, in March, 1913.

also due in part to differences in environment, circumstances, training —one sort of home-life being more favorable than another to progress through school, for example. Each advance in the study of individual

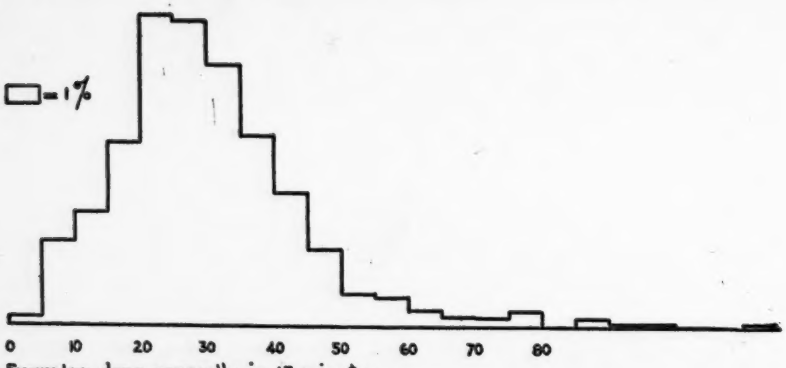

CHART 1. THE RELATIVE FREQUENCIES OF DIFFERENT DEGREES OF ABILITY IN ADDITION IN THE CASE OF FOURTH-GRADE PUPILS.

differences, however, shows that differences in maturity and differences in the circumstances of nurture account for only a small fraction of the differences actually found in individuals of the same general environment of an American city in 1900–1912. Long before a child begins

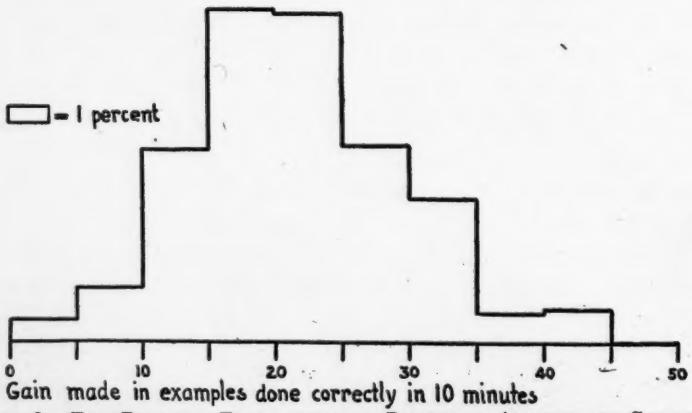

CHART 2. THE RELATIVE FREQUENCIES OF DIFFERENT AMOUNTS OF GAIN FROM FIFTY MINUTES OF PRACTISE IN DIVISION, IN THE CASE OF PUPILS OF THE SAME SCHOOL GRADE.

his schooling, or a man his work at trade or profession, or a woman her management of a home—long indeed before they are born—their superiority or inferiority to others of the same environmental advantages is determined by the constitution of the germs and ova whence they spring, and which, at the start of their individual lives, they *are*.

Of the score or more of important studies of the causes of individual

differences which have been made since Francis Galton led the way, I do not find one that lends any support to the doctrine of human initial

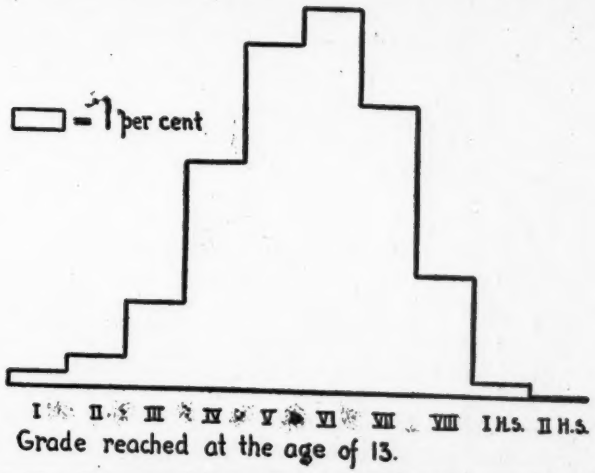

CHART 3. THE RELATIVE FREQUENCIES OF DIFFERENT AMOUNTS OF PROGRESS IN SCHOOL OF THIRTEEN-YEAR-OLD CHILDREN.

equality, total or approximate. On the contrary, every one of them gives evidence that if the thousand babies born this week in New York City were given equal opportunity they would still differ in much the same way and to much the same extent as they will in fact differ.

We find, for instance, that the children of certain families rank very much higher in certain psychological tests of perception, association and the like, than the children of certain other families. Now if this difference were due to the difference between the two groups of families in environment—in ideals, customs, hygienic conditions and the like—it should increase greatly with the age of the children in some rough proportion to the length of time that they are subject to the beneficent or unfavorable environment. It does not. One family's product differs from another nearly as much at the age of 9 to 11 as at the age of 12 to 14.

Again, if inequalities in the environment produce the greater part of these differences, equalizing opportunity and training should greatly reduce them. Such equalization is found by experiment to reduce them very little, if at all. Chart 4 shows, for example, the result of equal amounts of training applied to two groups of adults whom life in general had previously brought to the conditions shown at the left of the chart. The trait chosen was addition; from life in general one group had gained the ability to do twenty-seven more additions per minute than the other group, accuracy being equal in the two groups. At the end of the special training the superior individuals had gained on the average 28 additions per minute, while the inferior individuals gained

only 10 additions per minute. As a result of this partial equalization of opportunity, the superior individuals were farther ahead than ever! If equality of opportunity has no equalizing effect in so easily alterable a trait as rapidity in addition, surely it can have little power in such

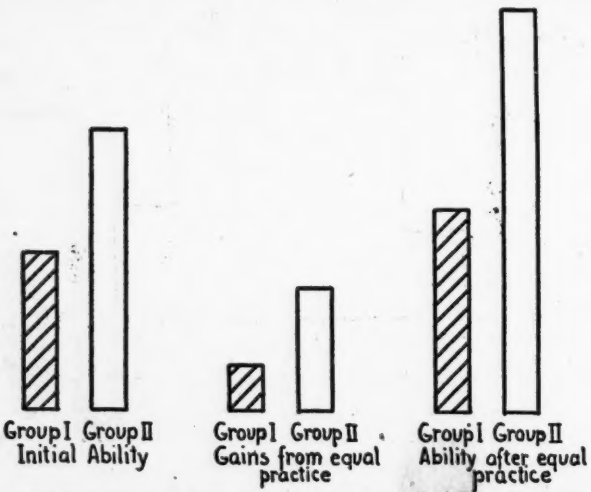

CHART 4. THE RELATION OF THE GAINS FROM EQUAL AMOUNTS OF PRACTISE IN THE CASE OF INDIVIDUALS OF HIGH AND LOW INITIAL ABILITY.

traits as energy, stability, general intellectual power, courage or kindliness.

Men differ by original nature. With equal nurture of an inferior sort they progress unequally to low stations; with equal nurture of a superior sort they progress unequally to high stations. Their absolute achievements, the amounts of progress which they make from zero up, are due largely to the environment which excites and directs their original capacities. Their relative achievements—the amounts of progress which they make, one in comparison with another—are due largely to their variations one from another in original capacities.

The man's original nature, too, has large selective power over his environment. The thousand babies will in large measure each create his own environment by cherishing this feature and neglecting that, amongst those which the circumstances of life offer. As Dr. Woods has well argued, the power of the environment to raise or lower a man is very great only when the environment is unavoidable. We must remember that one of these babies, if of mean and brutal nature, can by enough pains avoid industry, justice and honor, no matter how carefully he is brought up; and that one of them of intellectual gifts can, if he cares enough, seek out and possess adequate stimuli to achievement in art, science, or letters, no matter how poor and sordid his home may be.

If, a hundred years ago, every boy in England could have had as

good opportunity—each of the sort fitted to his capacities—as Charles Darwin had, the gain for human welfare would probably have been great; but if every boy then could have had as good inborn capacity for science, art, invention, the management of men—or whatever his strongest capacity was—as Charles Darwin had for science, the gain for welfare would certainly have been enormous.

The original differences in intellect, character, and skill which characterize men are related to the families and races whence the individuals spring. Each man's original mental constitution, which so largely determines how much more or less he will do for the world's good than the average man of his generation, is the product of no fortuity, but of the germs of his parents and the forces which modify the body into which they grow—is the product, as we are accustomed to say, of heredity and variation. The variation within the group of offspring of the same parents is large—a very gifted thinker may have an almost feeble-minded brother—but the variation between families is real. A feeble-minded person's brothers will be feeble-minded hundreds of times as often.

The general average tendency of the original intellectual and moral natures of children to be like the original natures of their ancestry is guaranteed beforehand by the accepted principles of biology. Direct evidence of it is also furnished by investigations of the combination of original and acquired differences which human achievements, as they stand, display. The same studies which find differences of nurture hopelessly inadequate to account for differences of ability and achievement, find that original capacities and interests must be invoked precisely because achievement runs in families, and in a manner or degree which likeness in home training can not explain. Galton found that the real sons of eminent men had a thousand times the ordinary man's chance of eminence and far excelled the adopted sons of men of equal eminence. Woods has shown that, when each individual is rated for intellect or morals, the achievements of those sons of royal families who succeeded to the throne by paternal death and thus had the special attention given to crown princes and the special unearned opportunities of succession, have, in the estimation of historians, been no greater than those of their younger brothers.

Children of the same parents resemble one another in every mental trait where the issue has been tested, and resemble one another nearly or quite as much in such tests as quickness in marking the A's on a sheet of printed capitals or giving the opposites of words, to which home training has never paid any special attention, as they do in adding or multiplying, where parental ambitions, advice and rewards would be expected to have much more effect, if they have any anywhere.

Mr. Courtis, who has been assiduously studying the details of ability

in arithmetic in school children, finds, as one sure principle of explanation, the likeness of children to parents—and this even in subtle traits and relations between traits, of whose very existence the parents were not aware, and which the parents would not have known how to nurture had they known of their existence.

Dr. Keyes has recently made an elaborate study of various possible causes of the rate of progress of a child through the elementary school. He traces the effects of defective vision, of sickness, of moving from one school to another, and so on, but finds nothing of great moment until he happens to trace family relationships. Then it appears that certain families are thick with "accelerates," or pupils who win double promotions, whereas other families are thick with retarded pupils, who require two years to complete a normal year's work. Of 168 families, only 30 contain both an "accelerated" and a "retarded" pupil, whereas 138 show either two or more accelerates or two or more retarded pupils. The differences in home training are here not allowed for, but, in view of what has been found in other cases, it appears certain that the rate at which a child will progress in school in comparison with his fellows is determined in large measure before he is born.

In intellect and morals, as in bodily structure and features, men differ, differ by original nature, and differ by families. There are hereditary bonds by which one kind of intellect or character rather than another is produced. Selective breeding can alter a man's capacity to learn, to keep sane, to cherish justice or to be happy.

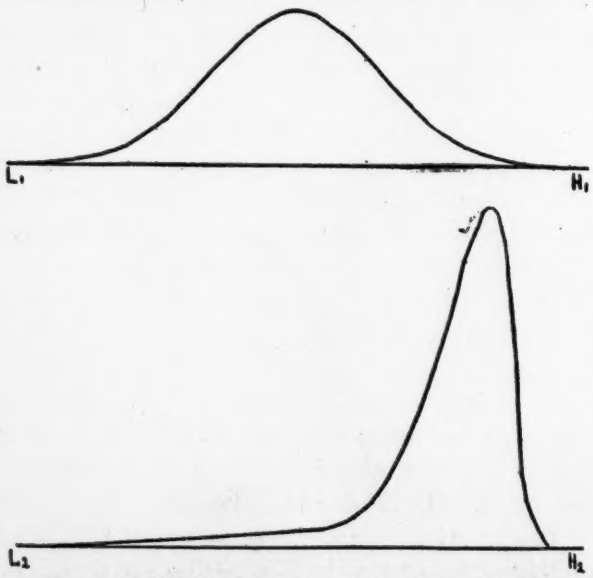

CHART 5. THE IMPROVEMENT POSSIBLE BY SELECTIVE BREEDING. The upper surface being taken to represent the existing distribution of intellect, the lower surface represents what might be expected from, say, ten or twenty generations of breeding exclusively from the apparently best tenth of human intellects.

Let the lines L_1H_1 and L_2H_2 in Chart 5 be identical scales for the original capacity for intellect, or virtue, or any desirable human trait. Let the surface above line L_1H_1 represent the distribution of this original capacity amongst men to-day. There is every reason to believe that wise selective breeding could change the present state of affairs, at least to that shown above L_2H_2, within relatively few generations. Perhaps it could do even more. There is every reason also to believe that each step of improvement in the original nature of man would, in and of itself, improve the environmental conditions in which he lives and learns.

So much for the general possibility of eugenics in the case of intellect, morals and skill—for what should soon be in every primer of psychology, sociology and education, and be accepted as a basis of practise by every wise family, church and state.

The next question concerns the *extrinsic* effects of selective breeding for intellect or for morals, the possibility of injuring the race indirectly by a change in, say, intellect which in and of itself is desirable. If we breed horses for speed, they are likely to lose in strength and vigor; do we run such risks in breeding men for intellect, or for morals, or for skill? This question has been neglected by the hortatory type of enthusiasts for eugenics. It has also not received the attention which it deserves from the real workers for racial improvement, probably because the psychological investigations which answer it are little known. They do, however, give a clear and important answer—that there is practically no chance whatever of injury from selective breeding within a race for intellect, or for morality, or for mental health and balance, or for energy, or for constructive ingenuity and skill—no risk that the improvement of any one of these will cause injury to any other of them, or to physical health or happiness. The investigations have found that, within one racial group, the correlations between the divergences of an individual from the average in different desirable traits are positive, that the man who is above the average of his race in intellect is above rather than below it in decency, sanity, even in bodily health. Chart 6 shows, for example, the average *intellect* of each of the groups, when individuals are graded 1, 2, 3, 4, etc., up to 10 on a scale for *morality*, according to Woods's measurements of royal families. I may add that the effect of chance inaccuracies in Woods's ratings, whereby one individual is rated as 8 or 10 when he should have been rated 9, or is rated 4 or 8 when he should have been rated 6, is to make this obtained and shown relation of intellect to morals *less close* than it really is.

Nature does not balance feeble-mindedness by great manual dexterity, nor semi-insane eccentricities by great courage and kindliness. Correlation of divergences up or down from mediocrity is the rule, not compensation. The child of good reasoning powers has better, not

worse, memory than the average; the child superior in observation is superior in inference; scholarship is prophetic of success out of school; a good mind means a better than average character. The fifty greatest warriors of the world will be above the average man as poets. The fifty greatest artists of the world will be better scientists than the average. Genius of a certain type does, *via* the nervous temperament, ally itself to eccentricities of a certain type; and very stupid men can not be rated as insane because they are already idiots; but on the average the most

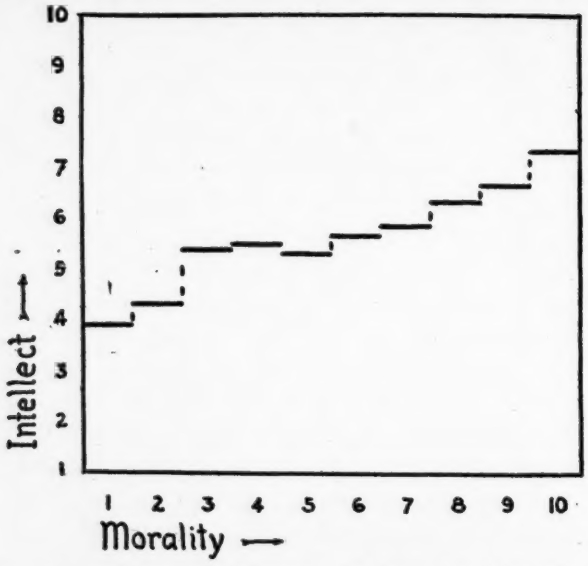

CHART 6. THE RELATION BETWEEN INTELLECT AND MORALITY IN EUROPEAN ROYAL FAMILIES. After Woods.

intellectual tenth of the population would, under equal conditions of strain, furnish fewer lapses into insanity than its proportional quotum.

Selective breeding for superior intellect and character does not then require great skill to avoid injurious by-products or correlatives of intrinsically good traits. *Intrinsically good traits have also good correlatives.* Any method of selective breeding, then, which increases the productivity of intellectually or morally good stock over that of poor stock, will improve man, with one possible added requirement—that breeding should be for fertility as well, should not be suicidal, should not make the race better, but at the same time put an end to it altogether!

It might be that there was a necessary inverse correlation in human nature between fecundity and high intellectual and moral station whereby, the better men became, the fewer offspring they would have; and whereby, at a certain limit of super-manhood, reproduction would cease. Certain changes of the birth-rate with time, and certain varia-

tions in it amongst groups, have given some students the impression that intellect, at least, is, by natural necessity, inversely correlated with fecundity.

It is hard to find the facts by which to either verify or refute the notion, current in superficial discussions of human nature and institutions, that such is the case. Sad testimony to man's neglect of the question which of all questions perhaps concerns him most—the simple question of which men and women produce the men and women of the future—is given by the fact that almost no clear and reliable evidence is available concerning the relations of fecundity to intellect, morality, energy, or balance. The most significant evidence is that collected by Woods in the case of royal families. Woods gives the number of children living till 21 in the case of each individual of the royal families which he studied. From them I have made the summaries noted on Charts 7 and 8. Each of these sets of facts is of course the

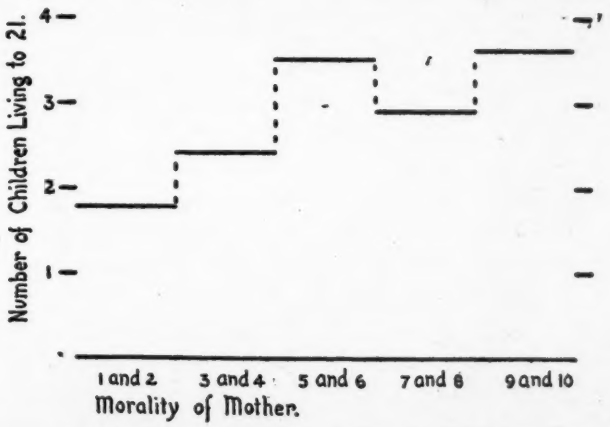

CHART 7. THE RELATION OF MORALITY OF MOTHER TO NUMBER OF CHILDREN.

result of the constitutional fecundity of the women in question plus certain very intricate cooperating circumstances; and neither can be taken at its face-value. What the birth rate would have been had the constitutional capacity of each woman worked under equal conditions, can only be dubiously inferred. My own inference from relevant facts concerning the studies of differentiated birth rates with which I am acquainted is that morality, mental health, energy, and intellect perpetuate a family, and that wherever the *really* better, or saner, or stronger, or more gifted, classes fail to equal the really worse, ill-balanced, feeble or stupid classes, it is a consequence of unfortunate circumstances and customs which are avoidable and which it is the business of human policy to avoid. Society may choose to breed from the bottom, but it does not have to.

No great ingenuity or care then seems necessary to make fairly rapid

improvement in the human stock. The task is only the usual one of any rational idealism—to teach people to want a certain thing that they ought to want, and to change social usages so as to satisfy this new want. The same sort of tuition whereby men are learning to want those

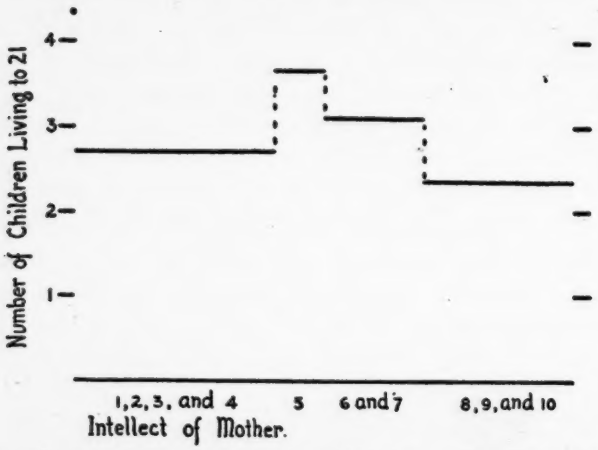

CHART 8. THE RELATION OF INTELLECT OF MOTHER TO NUMBER OF CHILDREN.

who are alive with them to be healthier, nobler and more capable, will serve to teach us to want those who are to live with our children's children to be healthier, nobler and more capable. Provided certain care is taken to favor the sane, balanced type of intellect rather than the neurotic, any selective breeding which increases the fecundity of superior compared to inferior men, and which does not produce deterioration in the physical and social conditions in which men live, will serve.

The danger of deterioration in physical and social conditions from breeding for intellect and morals is trivial. The effect is almost certain to be the opposite—an improvement in physical and social conditions. The more rational the race becomes, the better roads, ships, tools, machines, foods, medicines and the like it will produce to aid itself, though it will need them less. The more sagacious and just and humane the original nature that is bred into man, the better schools, laws, churches, traditions and customs it will fortify itself by. There is no so certain and economical a way to improve man's environment as to improve his nature.

Each generation has of course to use what men it *has* to make the world better for them; but a better world for any future generation is best guaranteed by making better men. Certain worthy customs of present civilization may be endangered by rational control of who is to be born, though this seems to me unlikely. In any case, we may be sure that if the better men are born they will establish better customs in place of those whose violation made their birth possible.

It is not by a timid conservatism sticking to every jot and tittle of the customs which gifted men of the past have taught the world, that we shall prevent backsliding: it is far safer to trust gifted men of the present and future to keep what is good in our traditions, and to improve them. The only safe way to conserve the good wrought by the past is to improve on it.

It is beyond the province of this lecture to devise biologically helpful and socially innocuous schemes of selective breeding, but I may be permitted to record my faith that if mankind to-day really wanted to improve the original nature of its grandchildren as much, say, as it wants to improve the conditions of life for itself and its children, and believed certain facts of biology and psychology as effectively, say, as it believes that wealth gives power or that disease brings misery, appropriate schemes for selective breeding would be devised well within the span of our own lives.

Any form of socially innocuous selective breeding will improve the stock by reproducing from those members of it who have shown, by ancestral and personal achievement, with due allowance for favorable or unfavorable circumstances, the superiority of the germ plasm which they bear. But some forms may be far more effective than others according to the way in which the original components of intellect, character, energy, skill, stability and the like in the germs are constituted. Suppose, for example, that the original germinal basis for human intellect consisted in the presence of a certain constant something, call it "I_n, the determiner for intellect," in the germ or ovum. The fertilized ovum, which is the human life at its beginning, could then have I_n double, if both the germ and ovum had it; I_n single if one or the other had it; or could lack I_n, as it must if neither had it. Suppose that the consequences of these three conditions were that the I_nI_n individuals would tend, with fair conditions in life, to be specially gifted; that the I_n individuals would tend to be of "normal" intellect; that the individuals lacking I_n would tend to be feeble-minded. It is then the case that of the germs produced by the individual who had I_nI_n at the start of his life, each contains I_n, that of the germs produced by the individual who had I_n at the start of his life, half have I_n and half lack it, and that of the germs produced by the individual who lacked I_n at the start of his life, no one has I_n. Consequently, by discovering the individuals who lacked I_n at the start of life and preventing them from breeding, we could rapidly reduce feeble-mindedness. By discovering the individuals who had I_nI_n at the start of life and breeding exclusively from them, we could eradicate feeble-mindedness and ordinariness both, leaving a race of only the specially gifted. The discovery could be made in a few generations of experimental breeding; and the exclusion, of course, could be made one generation after the discovery.

This supposition will be recognized by many of you as a simplified case of Mendelian inheritance of a unit character due to the presence or absence of a single determiner which can either be or not be in a germ or ovum, and which "segregates."

No case quite so simple as this can be true of human intellect, but something approximating it has been suggested as perhaps true.

Suppose, on the other hand, that the germinal basis for intellect consists in the presence, in the germ or ovum, of one or more of four determiners—I_1, I_2, I_3 and I_4—contributing amounts 1, 2, 3 and 4 of intellectual capacity. The fertilized ovum could then have any one of 256 different constitutions ranging from the entire absence of all these determiners to the presence of each one "duplex"—*i. e.*, in both germ and ovum. If such duplex presence meant that the two contributions combined additively, the original intellect of the individual could range from 0 to 20. Individuals, all of one same original intellect—10—might be of very different germinal constitutions, and so of very different possibilities in breeding. If two individuals, each of original intellect 10, were mated, it might be the case that their possible offspring would range in intellect from 0 to 20, or it might be that they could not go below 8 or above 12.

If the number of germinal determiners of intellect is increased to five or six, the task of telling the constitution of the germs produced by any individual of known original intellectual capacity is enormously increased; and the research needed to guide the best possible breeding of man is very, very much more laborious. Moreover, instead of hoping to bring man to the best possible status (subject to the appearance of new desirable mutations) by a few brilliant rules for marriage, we must then select indirectly and gradually by parental achievement rather than directly by known germinal constitution, just as animal and plant breeders had to do in all cases until recently, and just as they still have to do in many cases. Only after an elaborate system of information concerning family histories for many generations is at hand, can we prophesy surely and control with perfect economy the breeding for a characteristic which depends on the joint contributions of five or six determiners. For it is just as hard to "breed in" a determiner that raises intellect or morality only one per cent. as it is to "breed in" one which raises it a hundred per cent.—provided, of course, the latter determiner exists. And it is thousands of times harder to discover the distribution of a determiner in the human race's germs when it is one of ten that determine the amount of a trait, than when it is one of two.

The germinal determination of intellect, morality, sanity, energy or skill is, so far as I can judge, much more like the second complex state of affairs than the first simple one. Important observations of the inheritance of feeble-mindedness and insanity have been made by Daven-

port, Goddard and Rosanoff, which they interpret as evidence that original imbecility is due to the absence of a single determiner, and that an originally neurotic, unstable mental organization is explainable almost as simply. It is with regret that I must assure you that these observations are susceptible of a very different interpretation. Much as I should like to believe that these burdens on man's nature are each carried in heredity in a single package, which selective breeding can shuffle off in a generation or so, I can not. A eugenics that assumes that intellect, morality, sanity and energy are so many single niches in the germs which selective breeding can, by simple transfers, permanently fill, is, I fear, doomed to disappointment and reaction. I dare to believe that the time will come when a human being idiotic by germinal defect will be extinct like the dinosaur—a subject for curious fiction and for the paleontology of human nature; but I have no hope that such a change can be made with the ease with which we can change short peas to tall, curly-haired guinea pigs to sleek, or plain blossoms to mottled ones.

There is another fundamental question whose answer is needed for the most economical selective breeding of human nature, a question which time permits me only to mention, not to describe clearly. Stated as a series of questions, it is this: Do the germs which a man produces —his potential halves of offspring—represent a collection peculiar to *him,* or only a collection peculiar to some *line,* or *strain,* or *stock,* or *variety,* of mankind of which he is one exemplar?

Suppose a hundred men and a hundred women to exist, each with identical germinal constitutions, so that, say, in every case one tenth of the germs (or ova) would be of quality 5; one fifth, of quality 6; two fifths, of quality 7; one fifth, of quality 8; and one tenth, of quality 9. Suppose that they mated and had five hundred offspring. Suppose that the best fifty of this second generation married exclusively among themselves; and similarly for the worst fifty. Would the offspring of *these* two groups differ, the children of the best fifty being superior to the children of the worst fifty? Or would this third generation revert absolutely to the condition of the grandparental stock whence they all came; and be alike, regardless of the great difference in their parentage?

Does the selection of a superior man pay because his superiority is, in and of itself, a symptom of probable excellence in his germs; or only because his superiority is a symptom that he is probably of a superior "line" or strain?

That the second answer of each pair may be the true one, is a natural, though not, I think, an inevitable, inference from the work of Johanssen, Jennings and others. They have found selective breeding within any one pure line futile, save when some peculiar and rare variations have taken place within it. Their work is of very great importance and

forms the best introduction to the general problem of the limits to human racial improvement. I regret that time is lacking to describe these studies of heredity within one "pure line." It is from such that eugenics may hope to learn valuable lessons in economy of effort and exactness of expectation. I have, however, already taken too much of your time with the problems of the exact laws whereby good men have good offspring and whereby breeding for strength, wisdom and virtue may be most effective.

In the few minutes that remain let me sum up what might perhaps have been entitled the A B C of eugenics in the realm of mind.

I have tried to show that, in intellect and character, men differ, by original nature, in some sort of correspondence to the ancestry whence they spring, so that by selection of ancestry the intellect and character of the species may be improved; to show also that injurious by-products of such selective breeding are very easily avoided, if indeed they occur at all; and, finally, to state some of the problems whose answers will inform us of just how the original intellect and character of one man does correspond with that of his ancestors, and so of just the best ways to discover the best strains and to perpetuate them.

I hope to have made it clear that we have much to learn about eugenics, and also that we already know enough to justify us in providing for the original intellect and character of man in the future with a higher, purer source than the muddy streams of the past. If it is our duty to improve the face of the world and human customs and traditions, so that men unborn may live in better conditions, it is doubly our duty to improve the original natures of these men themselves. For there is no surer means of improving the conditions of life.

It is no part of my office to moralize on these facts. But surely it would be a pitiable thing if man should forever make inferior men as a by-product of passion, and deny good men life in mistaken devotion to palliative and remedial philanthropy. Ethics and religion must teach man to want the welfare of the future as well as the relief of the cripple before his eyes; and science must teach man to control his own future nature as well as the animals, plants, and physical forces amongst which he will have to live. It is a noble thing that human reason, bred of a myriad unreasoned happenings, and driven forth into life by whips made æons ago with no thought of man's higher wants, can yet turn back to understand man's birth, survey his journey, chart and steer his future course, and free him from barriers without and defects within. Until the last removable impediment in man's own nature dies childless, human reason will not rest.

EDUCATION THROUGH READING

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THERE is a wide variety of motives any one of which may lead a person to become a reader. Sir John Herschel wrote:

> Were I to pray for a taste that should stand me in stead under every variety of circumstances, and be a source of happiness and cheerfulness to me during life, and a shield against its ills, it would be a taste for reading.

A Suwanee reviewer deals with reading as an elegant pastime, the mental profit yielded by it being considered incidental. The reading of books as he thinks of it is to be classed with the viewing of pictures, a sort of esthetic exercise, delightful, uplifting, cultivating and, incidentally, informing, not resorted to, however, for the sake of information, at least not primarily for the sake of this, but for the refined pleasure to be derived from the exercise.

Reading for pleasure and diversion is perfectly legitimate when people have time and inclination for this; and it is well to urge those having time for it to cultivate also the inclination; but that is not the aspect of reading to which we would draw attention now. It is proposed to discuss reading as an earnest occupation, carried on with the direct purpose of drilling and storing the mind, its pleasurable and esthetic results, important as they are in themselves, being quite secondary. The theme, then, is reading as a distinct, invaluable, and too little recognized educational resource.

Consider first the very great encouragements to reading which now exist, and then note certain methods for responding to these encouragements, for utilizing the magnificent and ever-improving opportunities to read profitably opened to all in our modern life.

A cordial invitation to wide reading is extended by the presence all about us of ample literature, representing every department of thought, in forms perfectly convenient and incredibly cheap.

Carlyle said:

> Of all things which men do make here below by far the most momentous, wonderful and worthy are the things we call books.

And Macaulay:

> I would rather be a poor man in a garret with plenty of books than a king who did not love reading.

"Oh for a booke and a shady nooke,
Eyther in doors or out,
With the green leaves whispering overhead,
Or the street cryers all about.

"Where I may read all at my ease
Both of the new and old,
For a jolly good booke wherein to looke,
Is better to me than gold."

Not to speak of good old books, to be had in the stalls for a song, of the newspapers, which contain not a little good reading matter, especially in their Sunday editions, or of the innumerable magazines better and worse, there are editions of nearly all the world's literary masterpieces which are low-priced enough for the poorest and at the same time elegant enough for all but the most fastidious. You can find low-cost library editions and five-cent pocket editions, well printed, on good paper, with readably large type, suitable for all the demands of any undergoing the pangs of literary thirst. Not alone the masterpieces are so represented; but thousands of less pretentious though very useful books. Good reading matter is almost thrust upon us now.

This vast literary treasury contains riches from every gold-bearing region of the earth. The best specimens of antique and of foreign letters are there, having been translated into our tongue, in most cases, by capable scholars, and thus rendered accessible to such as read only in English. The best works of Plato and Aristotle, of Cicero, one of the world's greatest literators, of Boccaccio, Petrarch and Dante, of Leibnitz and Kant, Schiller and Goethe, indeed of all the mightiest German, Italian and French writers, can not only be read by us all at our leisure but can be owned by nearly all who would wish to own them.

This is no argument against learning foreign languages. Not every good product of foreign pens has been Englished. To become acquainted with the most recent best things written abroad you must read the originals. It is true, further, that no translation ever made or ever possible can carry with it across the chasm separating tongue from tongue the entire meaning, or the delicate shades of meaning, or the rich stylistic aroma, of a true literary work. It is nevertheless a benediction of the first order that in so many cases where we can not consult a literary original, we can possess ourselves of the author's main thoughts. Petrarch and likewise Keats read Homer in translation. If we can not topographically survey a country, scanning intimately its by-ways, it is worth a great deal to be able to travel leisurely its highways.

Besides the cheap edition and the translation, there is the free library. Those who are or think they are too poor to purchase much literary material, can, in any considerable center of population, find and

read all that they need of it in some public library, without money and without price. The public libraries in the principal cities offer the most ample and inviting opportunities for reading, and these opportunities are growing richer every year. Public libraries are enlarging and new ones opening. In nearly every state, a Library Commission is planting libraries in small places and carrying traveling libraries to the remotest hamlets. Quite as important, librarians are mastering their trade, becoming more and more able to make libraries available to such as use them.

The opportunities for securing information and culture through reading, which are now presented by low-priced editions, good translations and free libraries, constitute, together, a potent appeal to us to read.

Another such appeal lies in the certainty that by properly using these privileges any one of us can become a well-informed, well-educated person. "Reading makes the full man," says Francis Bacon.

Says Lecky ("Map of Life, Conduct and Character"):

> While the tastes which require physical strength decline or pass with age, that for reading steadily grows. If it is judiciously managed reading is one of the most powerful means of training character and disciplining and elevating thought. It is eminently a pleasure which is not only good in itself but enhances many others. By extending the range of our knowledge, by enlarging our powers of sympathy and appreciation, it adds incalculably to the pleasures of society, of travel, of art, to the interest we take in the vast variety of events which form the great world-drama about us. To acquire this taste in early youth is one of the best fruits of education, and it is especially useful when the taste for reading becomes a taste for knowledge, and when it is accompanied by some specialization and concentration and by some exercise of the powers of observation.

Mere reading by itself alone can of course never produce the ideal education. Reading can not wholly take the place of schooling. The seminary, student conferences and debates, the class, class drill, oral explanations from arousing and able instructors, the inspiration which each student derives from the student body about him, and the other thousand and one stimulating associations connected with every good school, exert an influence which books and reading are powerless to produce. One who has never been subject to these influences, be he the most omnivorous and painstaking reader in the world, is unfortunate. Get all the schooling you can. If possible couple it with your reading. Irregular schooling is better than none, and so is a poor teacher. None of us are too old or too learned to be benefited by a term or a course of lessons or lectures in school, college or university. However, if you have never been able to avail yourself of these excellent aids in the training of mind, and if you are now and henceforth unable to do so, do not despair. You can read, and your chances are enviable.

Studious, persistent familiarity with noble letters will place you among the knowing, and it is worth all the effort it can possibly cost you. It will give you, if not the ideal education, a real education, broad, full, useful, enjoyable, a fortune which wealth could not buy. It will keep you from being a boor and make you a cultivated person instead. You may grow to be a connoisseur, a critic, an authority in some department of literature, philosophy, art or science. If you persist, though no degree ever crown your attainments, you may yet be able to instruct masters and doctors. Short of this, the possibilities of profit from reading are indefinitely rich and great. It is a sort of mental suicide if we neglect them.

In these last words, to make the argument specially strong, we have been supposing the case of the people who possess little or no school training. But such as have enjoyed that training, however long, ought nevertheless to appreciate the advantages of reading. If familiarity with books can not take the place of mental drill, no more, certainly, can mental drill take the place of familiarity with books. If you already possess a good foundation laid in school build upon it by reading. The chances of profiting in this way ought to impress you as much as if you had been less fortunate in respect to schooling.

The existence of low-cost editions and of excellent translations of good books, made accessible through free libraries and otherwise, is calculated to bring to bear upon us all a moving incentive to read. If we yield to this incentive, whoever we are and whatever mental advantages we may have enjoyed hitherto, the result will be invaluable mental cultivation and improvement.

Some one will interpose: "I do not love to read; it is a bore. I hate books. If I am to get good from reading you must tell me how I may develop interest in them."

How sad the confession that one does not love to read. Compare Edward Gibbon's avowal that he would not exchange his love of reading for all the gold of the Indies.

Two sorts of people avoid reading, those with very little intelligence and those possessing such unusual intelligence and originality that their minds keep busy without external stimulus. The dull ones can not perhaps be helped much; the others need only proper direction in order to find good reading a perpetual delight.

An intelligent person who dislikes reading is nearly sure to be deeply interested in something; in games, in hunting, in some kind of animals or sort of mechanism. Get a first-rate book discussing his hobby and see if you can not bait his taste therewith. Most likely he will read that and call for another and another. These books will suggest still others and your man is a reader.

If all such traps fail, get your protégé to read a thrilling short

story, or touch him with a live coal of patriotic verse like Oliver Wendell Holmes's

> Ay, tear her tattered ensign down,
> Long has it waved on high,
> And many an eye has danced to see
> That banner in the sky.

With this poem should always go a brief historical account of its interesting origin and effects.

No matter, at first, how ill-written the novel may be, if only it is fetching. One of Conan Doyle's "Adventures of Sherlock Holmes" would well fulfill this office. If a man were not interested in these pieces you would be justified in giving him up. But most would be interested. The story would catch the mind and launch it, and the good work would be begun. Well begun would in this case be far more than half done. From the short story the learner would pass to higher and better story themes out into prose fiction at large and into poetry. After a while he would need no more attention, as the novel he began with might lead to the reading of historical novels, histories and essays, placing him upon a literary life, proving independent and happy in that direction.

Let us now go on to inquire how we can effectively respond to the incentives impelling us to read, how utilize the facilities for reading made available by modern conditions, how gain the mental advancement which reading may bring.

One precept to this end is: save the scraps of your time. Diligently hoard and use those odds and ends of hours which so easily run to waste and which most people let run to waste. Five minutes once or half a dozen times a day, after rising, before retiring, waiting for meals, at recess or during some other lull in school work, now pass unimproved, which are probably salvable by nearly every one. Such bits of time are eminently suitable for memorizing choice verse. One reader thus imbibed the following draught of nectar from an Irish poet named Davis:

> Sweet thots, bright dreams my comfort be,
> I have no joy beside;
> Oh, throng around and be to me,
> Power, country, fame and bride!

On holidays many throw away whole hours together. In most cases such lost instants make up in the course of a year several days, perhaps weeks, which ought to be turned to profitable account.

Few can afford the eyesight strain necessary to read in railway carriages; but a well-lighted railway station, if you happen to be detained in it, is an eminently fit place for reading. Against such occasions, more or less frequent in every life, always go equipped with a pocket

edition of some choice author. "A book of verses underneath the bough" or whereever else you camp is a fitting companion.

In urging this employment of spare fragments of time, we are not forgetting the need which all have of recreation. Our bodies must of course be rested when they are weary, and so must our minds. Time spent in reading when you are too tired to read is not saved, but lost. The most healthy person sometimes needs the fullest possible relief from mental exercise, and that during the day. For all this it is true that change of mental activity, as from our regular work to a delightful book, affords mental rest of a most valuable order. If your dinner is ten minutes late you need not take up Euclid or the "Principia." Use Thackeray, or even a comic paper.

A second precept toward utilizing one's reading opportunities is: Carefully select your matter. Here comes up the very important question, what to read. Answer: In the first place, negatively, it does not pay to spend much time upon newspapers or upon ordinary magazines. Not that one may not fish up from these great seas now and then a pearl; but that the average time and labor cost of such pearls is too great. Also eschew ordinary fiction and ordinary poetry, save now and then an hour when the mental alimentary canal, lacking tone, can keep down nothing but broth. Life is too short to read all that is truly excellent; it is certainly too short to read much of what is just passable.

Read more books and less periodical literature. A bad habit has arisen in this matter. The great ability, along with the timeliness, of many magazine pieces now, has had the unfortunate effect of turning readers from board to paper covers. A new book we ignore because *Book Notes* or the *Critic* or the *Dial* or the *Outlook* or some other sheet has had a review of it. But the best possible review of a book is no substitute for the book. As well dine upon odors from a hotel kitchen. Read all the reviews that appeared upon Lecky's "History of England in the Eighteenth Century"; then take time and go through the work itself. You will find it a new world. Equally great is the error men make in reading so few old books. A few years ago it was found, by questioning, that only one out of a class of a hundred and ten college seniors knew anything about Milton's prose works. Many who consider themselves fairly well read have never touched Bacon's "Essays" or the "Pilgrim's Progress." Such as do read many books, among them, too, books which came out before the Spanish War, often mistakenly avoid the most precious works because they are bulky. To master Masson's "Life of Milton" or Spedding's "Life of Bacon" is a liberal education. It is at once a wonder and a misfortune that so few essays are read now. The rage is all for poetry instead. Colleges and universities offer a hundred lectures on poetry to one on prose *belles lettres*. So far as one can observe, the noble essays of Hume,

Macaulay and Montaigne are nearly forgotten. Interest in this class of literature should be revived.

Rarely has a busy man or woman the time to peruse the whole of an author, however famous. It would rarely be of use to read wholes, even with amplest leisure. It is the mark of a great writer to have uttered a good deal of trash; and it is almost a sure proof of a reader's pedantry if he has read all which a given author has published, unless he has done so to hunt up errors or peculiarities. It shows that he has read not *con amore,* but merely that he might boast. Too many read just to be able to say they have read. The desire of reputation for attainments often outruns the desire for attainments. One young lady who said she had read Shakespeare was asked if she was familiar with Romeo and Juliet. She replied that she had often read Romeo, but that Juliet was somehow always out of the library when she called for it.

As already said, we can not read all even of the best; which remark naturally forces a search for some principle or principles by which to make selection. Two principles suggest themselves, one objective, the other subjective. The objective one is that the very greatest classics in the world's literature, Homer, Plato, Dante, Shakespeare and Goethe, should be more or less familiar to all. The subjective principle is: Consulting your occupation or your bent, select some specialty in letters and do your main reading with reference to that.

If you are a member of a profession your stock and standard reading ought to be related to that profession, not narrowly, of course, but generally, in a way to give life, breadth and atmosphere to your daily toil, relieving the tedium of homely tasks and spreading a hue of intelligence over business which but for this might seem leaden. Every great branch of mental work by which men earn bread has, besides the technical volumes which set forth its laws, a side literature, little technical, which connects it by a seamless web with polite letters. This is the library where a professional man should do his main reading.

A teacher, for instance, who has to teach literature or history should, for general reading, cultivate literature or history at large. The course to pursue in these cases is obvious. But how if chemistry or physics, or biology is your department? In such a case read the history of the science and of science in general, the biographies of great scientific discoverers and the excellent fiction and verse to which scientific men and scientific interest have given birth. Thus a physiographer would read, among other things, Shelley's "Cloud"; perhaps also his "Ode to the West Wind." There is no more interesting and there is no more valuable reading than well-written biographies of scientific men. The history of scientific discovery widens into the history of discoveries in general and this into the history of civilization.

If you have no profession, being only a person of leisure, let your

reading follow your bent. Deal with poetry or essays, with history or science, with philosophy or art, as may best suit your fancy. Make yourself an authority on some particular author or cluster of authors, or upon the literature of a race or of a century. In a case of this sort the cautions to be observed are: Keep your reading unitary and systematic, and do not try to cover too much ground. If you have no bent, read history and biography.

One means, then, to the utilizing of opportunities for reading is: Hoard, miserly, your minutes; and another is: Choose carefully your matter. We now go on to speak of a third means, and it is: Methodically digest and conserve; methodically conserve and digest. Either form of phrasing the rule is correct, for we conserve our mental attainments by digesting them and we digest them by conserving.

Many people read vastly, yet never have much to show for it, because they trust to interest and memory to retain what ought to stay with them, using no method for assisting memory. It is a great mistake. Memory is invaluable, of course, and should be hard worked. The exercise of piling up in one's memory nuggets of literary gold can not be commended too highly. Still, the reader who employs no mnemonic apparatus, no mechanism, no ways and means for supplementing memory work, is an intellectual prodigal. What means or contrivances can be suggested for conserving and digesting the useful matter with which reading supplies the mind?

We must learn to assort as we read, to attend to what has meaning for us and pass lightly over the rest. "Some books," says Bacon, "are to be tasted, others to be swallowed, and some few to be chewed and digested." Few books are worth reading word for word. Much can be skipped without loss. Many a good book is of such a character that if you begin by carefully perusing the preface and table of contents, so as to discover the author's train of thought, you can read the rest at the average rate of three or four pages per minute. This reading at a gallop is a knack into which one grows by long practise. You gradually acquire a feeling for what you want and fix the mind on that alone. Thought is thus freer to master "for keeps" the passages deserving this, which is as important as the ignoring of the rest. The question, "Understandest thou, then, what thou readest?" is as pertinent as it is old.

Take notes in reading, partly to fix attention, helping you recall in general what you may never need or care to recall in detail, and partly to make fast for future consultation the matters which most forcibly impress you. No one can tell you, and you can not prescribe to yourself, when, upon what occasion, upon what sort of a passage to take a note. Feeling, prescience, second sight, must guide. Many data that you put down will never seem to profit you, but the note-taking may be

no whit the less valuable for this. Thought going into the mind may change form, as food turns into blood, but it is never lost.

However, though the jotting down of impressions against paragraphs read is never, in itself, useless, it is none the less proper to warn you against writing too many of these memoranda. Very frequent or very long pauses for that purpose not only consume time but also interrupt interest and dim the impression made on you by the author's thought as a whole. Moreover, it is pleasant to reflect that the older you grow in the reading business the less you will need to remit reading for the sake of a note and the less likely you will be to do so unnecessarily. Take notes, then, but not too many.

Notes should be written in ink, legibly, each with careful reference to book, chapter and paragraph or page. You will never know which of your many entries you may by and by wish to appeal to, and it would be a pity in time of need, to have aid near, of which, owing to negligent writing, you could not avail yourself. Use for notes very ordinary blank books, or pads, of good paper, writing on only one side of a leaf, so that each leaf may be readily detached if necessary. Take notes, not many, but few, perfectly plain, and on easily detachable leaves.

We have been explaining that the reader must "take" notes: We now urge that he must "make" notes, by which is meant something additional and more important. The new point is this: that you should not be satisfied with thinking your author's thoughts after him, but should follow out all fertile suggestions made by him, into reflections of your own. Horace Bushnell used to say that he could never possibly read a book through. If it did not "find" him he threw it away on that account. If it did "find" him he was early beguiled by it into independent cogitations, which interested him more than the author's, so that he deserted the book on their account. These reactions of the readers's own mentality are the very best fruit of reading. Encourage them: give up to them: let them divert and master you. The book which drives you from itself by rousing you to amend, refute or amplify its teaching is precisely the book you need. It is life-giving food for your mind.

You here discover what was meant by the remark that we digest mental stores in conserving them and conserve them by digesting.

All thought-germs of your own, no less than the plants not your own that you culled from the other man's garden; the original matters no less than the memoranda, must be laid away, so many green flowers, for preservation in note-books. Use one and the same series of books for both sorts of products.

So far as you can manage it, whether with the notes you have taken or with the notes you have made, confine each note to one subject and to one page of the book, leaving the rest of the page blank. If a note

covers most of the page, leave the next page blank. If, in your hurry, you have written too much on a page, or have mixed two subjects in one note, take early opportunity to separate item from item, placing each on a page by itself. In making these adjustments and transfers, use scissors, write as little as possible, and make no fuss or parade of nicety. The entire operation of writing and registering notes—we can not too much emphasize this—should be as simple, informal and rapid as possible, lest the labor of it and the time consumed by it should disgust you with the plan.

Some day, after your notes have become a little voluminous, it will interest you to glance them over. You will be surprised at their richness, and nearly every item will appeal to you with greater zest than when you placed it there. Each that was more or less original at first will now sweep your thought further on, while nearly every mere registry of some one else's idea will now compel your mind to bring up ideas out of its own depths. Before you are aware you will whip out your fountain pen and begin to make additions. Your thought treasures will swell as you count the precious metal they contain; and this result will recur each time you take account of stock. You will often need to insert new pages. Just pin them in or paste them slightly at the edge, making the mechanical exertion of the process from first to last as simple and little tiresome as can be.

Later, you will some time be called on for an essay or a paper on some topic of which you are known to be fond. Turning through your notes you will find most that you wish to say all ready to your hand, needing only that you detach the proper leaves, bring them together in order, slightly amplified, it may be, and write neat bridges between them. Spurts of fresh and original cogitation will almost inevitably accompany this recension process, and these, of course, will not be rejected.

THE GENESIS OF PERSONAL TRAITS

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As a principle of evolutionary theory, it may be stated that the environment stands to the organisms within it in one group of relations during the long evolution of races and species. The part played by the environment in the development of an individual is equally important, but so unlike in character that it must be treated independently. Phylogeny and ontogeny are governed by their own laws; yet they are elements in one harmonious whole. If carefully studied, either will show the part objective conditions play in progress. I have already touched upon phylogenetic problems in earlier articles,[1] where I tried to show that while the inheritance of characters follows biologic laws, the release of characters takes place under the stimulus of environing conditions. The external environment is not active at conception or when characters are formed before birth. Each individual must be brought into contact with external conditions through his own experience to evoke the characters heredity has given him. He recapitulates the history of his ancestors with regularity; yet the biologic effects of this race experience may lie dormant within him, if external stimuli do not evoke them at the proper time. The individual in whom they are undeveloped is retarded, and shows in his conduct defects which in the contest of life put him behind other persons of like heredity but with a more stimulating environment.

The principles of ontogeny can not, however, be elucidated in this way. They are to be traced in the epochs of child development rather than in those of race evolution. If the environment has no influence, such studies are a waste of time; but if environing conditions have influence their power over the successive stages of child growth may be detected. The early stages will be less under environment control. But each later state would be more subject to the retardations and accelerations imposed by objective conditions. Each environmental shortcoming would be reflected in some personal defect; and every acceleration due to favorable conditions should be measurable in increased vigor. Men reflect their defects in appearance, their perfections are revealed in their activity not in their bodily structure.

In attempting to show the relation of environmental control to the various stages of child development I shall rely upon this principle. *Biologic characters* are positive and show themselves in normal persons. *Defects,* being negative, indicate the absence of characters or an imper-

[1] "The Laws of Environmental Influence," October, 1911, and "Types of Men," March, 1912.

fect development of them. A defective child goes through the stages of its development more slowly than the normal child, and fails to reach the later stages. Such a child has not a different heredity from the normal child, but simply a less complete expression of it. If this is true, defects measure environmental control. Every defect has some objective cause which acts as a check on normal growth. We make progress, therefore, in the study of defects as we connect them with bad environments.

We can thus detect physical defects. To ascertain and measure mental defects the needed criterion is found in the law of the association of ideas. If a mental defect has at its basis a harmful association of ideas, we may confidently affirm that its origin is environmental. All ideas are postnatal, and hence all associations must be formed after birth. We do not need a biologic character to create a new association of ideas, but only some reorganization of experience. In harmony with these facts and principles there should be four stages of child development, which appear in the following order:

1. The elementary life stage.
2. The sensory stage.
3. The stage of bone formation.
4. The motor stage.

On the basis of this analysis, there should be a type of man who has the elementary vital functions, but lacks the later organic developments. That such a type exists can be shown, and its indices readily pointed out. This type has high cheek bones, a sloping forehead, a flat, broad nose, and a defective lower face and chin. The central part of the face is fully developed, while its upper and lower parts are imperfect. The people of this type are short in stature, broad at the hips, and round-headed. All the vital functions are normally developed, but the later stages of growth are defective. Such people thrive in a simple environment, especially if they have a pictorial religion and a conventionalized morality.

A second physical type is also easily described. Here the upper part of the head is fully developed, and the central part of the face is defective; the nose is peaked and narrow at the base; the teeth are bad; the mouth is small; and the chin is pointed. This physical description has a meaning that can be readily interpreted. The retardation has taken place late in pregnancy after the brain has passed through its initial development. A child's face lengthens downward as the child matures. A weak, short lower-face indicates, therefore, a stoppage of growth after the middle-face and upper-face have been formed. A person of this type is likely to be short and thin and have a poorly developed bone structure. The type is usually regarded as intellectual when contrasted with the first type, which is often designated as sexual.

These differences among men are too plainly marked to be overlooked. The usual judgment is, however, that they are due to heredity. This claim I will not argue; I shall merely show that the differences lend themselves to another interpretation. As the mind goes through successive stages in its development after conception, may not each stage have an environmental complement which reacts on it and helps or hinders its growth? In any case, when we examine the two contrasted physical types from this point of view, some claims may be made as to their genetic meaning. The first type has been retarded early in pregnancy; the other at a later period. The retardation in the one case may be due to defective nutrition or excessive sex excitation; in the other it is perhaps the result of irritants in the mother's system. Facts that make satisfactory evidence in support of these suppositions are hard to obtain, but a justifiable theoretical position is taken by assuming that, in the one case, the child is carried an abnormally long time in the womb, while in the other birth is premature.

To render my classification clear it is important to contrast the stages in a child's development that occur before and after birth. The prenatal stages are physical, and physical defects are cases either of prenatal retardation or acceleration before birth. Postnatal development, on the other hand, is mainly mental, and mental defects have their origin in the association of ideas, which comes necessarily after birth. This simple distinction students of development fail to make; consequently, they confuse relations which would otherwise be obvious.

Let me carry my contrast one step further. The sensory development of a child is prenatal; the motor development is postnatal. The delay of motor development is due to the fact that bones are needed to serve as fulcrums on which the muscles act. These bones can not harden until after birth. The head is formed before birth; the bones solidify after birth. It is, of course, the difficulty of child-bearing that causes the delay of motor development. The sensory stage precedes the motor stage of growth by several years, and from this fact important consequences follow. At birth the sensory powers are fairly complete. The stomach is ready for food, and the circulatory system is active. The early impressions of the child come from these sources alone; it lacks the motor coordinations which make adjustment to the environment effective. Immediately after birth, all impressions are sensory, and are bound together by mental associations in which there are no motor elements. Such associations may easily become disjustive.

The mental life of a child should be pictured as arising from the activity of a number of partially organized psychic centers. Each center has stored up some latent energy which becomes active when adjacent centers are aroused. A stimulus started by any external disturbance excites these centers to activity with the result that a mental impression is formed. A succession of these arousals fix definite grooves along

which mental excitation moves. Trains of sensations thus arise which can not be called either adjustive nor disjustive. They move through the brain along the line of greatest surplus energy and of themselves yield results of neither value nor detriment. The child would live, think, remember and forget; he would neither gain nor suffer by this automatic thought. Only after bones grow can it make the motor coordinations on which adjustment depends.

Very different effects follow strong, vivid impressions to which the motor powers are not ready to respond. These strong stimuli passing over into action prematurely tax the motor organs and disarrange them. Such effects are permanent, and *motor strains* are brought on that render future development abnormal. When a child walks too soon, the strains are readily seen, and it is generally recognized that the ill effects endure. If this is true of a child a year old, would not strong mental excitement in a child four weeks old produce even greater disorders, disturb motor development, and, reacting on the mental life, make it abnormal? Mental disorders are usually interpreted as wrong association of ideas bound together by strong sensory connections. The derangement is thought to be confined to the sensory system. The disorders are, however, not sensory, but motor. The premature activity of motor powers caused by sensory excitement produces strains that persist. The abnormal parts when excited arouse trains of thought that are disjustive. A strong person can repress them; he can even exclude them from consciousness; but when he sleeps or is weakened in any way, they intrude into his consciousness and disturb the normal flow of ideas.

Another way of presenting this thought is to contrast it with the theory of a subconscious mind. Here it is assumed that a sensory underworld exists in which ideas are stored. From this mental cavern, they break forth to disturb the normal consciousness on which adjustment depends. The connection between thoughts should not be associations, but movements. Subconscious trains of thought are in reality movements. They are, however, morbid disjustive movements, performed beyond the realm of consciousness. Could we really see what takes place, their motor origin would become apparent. The subconscious is a disjustive motor realm deprived of normal external connections.

Sensory excitement in an infant starts premature motor reactions which strains the unformed parts. It thus leaves permanent effects that appear in consciousness as disjustive trains of thought. There is thus a disjustive world in the background of every individual who has experienced sensory storms in infancy. The shock he then felt was not a shock to his mental associations, but to his motor coordinations. The child should live in his present sense impressions, and forget them when other agencies start new trains of thought. The lasting impressions have another origin. Strong stimuli, whether coming from the external

world or from internal disorders, arouse the partly formed motor centers and create in them an abnormal activity. Motor strains, bone displacements, muscular irregularities and undue local sensitiveness are thus caused, which force disjustive trains of thought into consciousness with each renewed activity. All such thinking must be suppressed before adjustment is effected.

Motor domination begins about the fourth year and ends ten years later. It is the means by which adjustment is secured. Sensory trains of thought are adjustive only when they help men to foresee the elements of future adjustment. Their usefulness comes after the motor adjustments are formed. Any reversal of this order produces a disjustment which is intensified if motor strains have been produced by the premature activity. These disjustments are due to the abnormalities of the child's environment and to wrong notions of education. Parents not only fail to guard their children against sensory storms, but they introduce artificial trains of thought under the mistaken notion that vivid concepts and well-organized memories are an aid in a child's development.

Environmental maladjustments thus have three leading causes: defective nutrition, poisons formed within the system, and premature motor activity. The first two are prenatal, the third is due to the later development of the motor than of the sensory powers. In their genetic manifestations these maladjustments show themselves as retardations, accelerations and motor strains. Their pathological effects become sex morbidness, senility and motor morbidness. As mental phenomena, they become egotism, dogmatism and mysticism.

Symbolism is an intense form of mysticism and beyond it are visions, hallucinations, subconsciousness and finally double personality. The essence of them all is the same. Some of the motor powers do not readily come under the control of the will. The amount of this disruption of personality varies, but its presence is always a manifestation of motor disorder.

The important facts to be recognized are the difference between senility and morbidness and the two distinct sources of morbidness, the one in sex disorders and the other in motor strains. Senility is a sensory condition making mental associations difficult or impossible to alter. The causes of morbidness lie not in the brain but in the body. It is thus a pathological, not a mental disorder. Morbid parts are easily excited to action and act apart from, or in opposition to, the dominant personality as expressed in the will.

To simplify this argument still more I shall divide mental reactions into three groups, visual, motor and senile. Visual reactions involve no movement of thought beyond itself. Motor reactions create thought movements which end in activity. Senile reactions create a sequence with no elements not found in antecedent mental concept. Colored

areas pass before us in visual thought. Limiting sequences follow one another in senile thought. The dominance of spatial concepts indicate premature sensory associations preventing the outward movement of thought to unexplored regions. The dominance of fixed sequences in thought reveals a lack of energy and of objective adjustment. Motor thought begins not in established mental associations but in bodily movements, aroused by external contacts. If movement precedes thought, action is adjustive; when thought determines movement abnormal mental states or senile limitations cause thought to flow on without any adjustive tests of its truth. Normally each thought should start a train of muscular activity leading to adjustment. Thought should be transformed into movement, and movement into thought. The morbid intensity of particular centers prevents this by forming a series of related ideas instead of transforming thought into movement. Visual or word repetitions are thus the marks of morbidness due to motor strains. This dance of sensory ideas with no accompanying activity is, however, regarded not as a defect but as an excellence. Such abnormalities are regarded as native powers when they should be recognized as acquired disjustments. Few readers will be willing to admit this. To do so would call into question conventional standards and strike at cherished literary and artistic concepts.

I can make my meaning clear by example better than by argument. When the American Academy of Political and Social Science was formed, President James and I had a discussion as to the title of the organization. He contended that the title should contain an "and," and I was equally firm in the opinion that the "and" should be omitted. He argued that without the "and" the scope of the society would not be regarded as comprehensive, while I asserted that with it the title would lack a definiteness in aim. It was a long time before I realized what was the real difference between President James and myself. I found that I, myself, was constantly tending to put "ands" in sentences and to pile adjectives on top of one another. When I made a short, crisp sentence I came back to it, thinking that I had left something out. This feeling was often so strong that I could not get away from the sentence until I had added something, or balanced it, as a rhetorician would say. I finally hit on the cause of my feeling, or at least an explanation that seemed satisfactory. The place where this tendency was strong was where the word had some closely related synonym, which, stored in my subconscious memory, strove to express itself and troubled me until I dragged it forth and made it a companion of the word I had used. If I had no double associations of words I wrote easily, but the flow of thought was checked at points where double associations existed. There I either expressed my thought twice or underwent a mental conflict until I drove the related word out of consciousness. The title to which I have called attention is an illustration of

this. One group of our societary associations is with Greece and another with Rome. *Political* Science brings up the one group of associations, *Social* Science the other. If a writer has but one set of associations, a single word will fully express his meaning; but if he *knows* two languages and has a double set of words, each must find expression to relieve the subconscious memory. A style of this nature is called literary. With the single set of expressions the writer seems abrupt. A complaint is often made that I am elliptical in expression. I doubt not that many a reader has said this already in reading this article. If, however, he will go back to the places where I seem to have left out some step in the sequence of the thought, he may find that at that point he has some double association of words that I have disregarded. A fluent writer says in each sentence, or at least in each paragraph, "my thought is so in Greek, it is so in Latin, and finally so and so in English." The good writer in this sense uses all the synonyms in his own or the reader's mind before he passes along to the next topic. He brings up the whole range of his reader's sensory associations instead of calling for will power to suppress them. Concise, straightforward construction demands will power to follow. Every idea is then expressed once and only once. Those who are dominated by sensory associations can not readily follow such a writer. Like birds they fly several times around a spot before lighting.

This means that an ornate style is a defect and not a mark of genius. The study of languages weakens the will, or, to state the thought in another way, it prevents the growth of motor coordinations. If so, children should not be taught two languages. Moreover, they should be corrected when they use many adjectives or words of more than two syllables. Only short, concise expressions can come quickly enough to aid a child in his decisions. Any delay in the formation of trains of thought retards action and prevents the growth of will power. Only the child who thinks more quickly than he acts can develop adjustive reactions and thus escape from the domination of sex and sensory associations. The effects of these double word associations are everywhere visible.

I shall offer additional illustrations from the field of art, where sex and sensory dominance also has a crushing power. Time and space can not be directly pictured in art; nor can rest and motion be portrayed. These relations are brought into consciousness only through associations with surfaces and lines. Pictures are either color masses, or perspectives taking the thought beyond the visualized surfaces to the real world back of them. Most pictures combine these two factors, surfaces and lines. The differences among pictures is in the proportion and relation of these factors. If the color masses are in the foreground, and the lines creating the perspective in the background, the picture indicates a sensory dominance on the part of its maker. If the lines

are in the foreground, and the surfaces are thrown into the distance by the perspective, the picture creates a motor impression and is admired by those with a motor dominance.

Colored surfaces stop the movement of the eyes and give relief to those with weak muscular adjustments. Lines keep up the muscular tension and give pleasure to those who because of strong eye muscles really enjoy eye tension. The movement and strain force the thought from the line into the indefinite background. We think of what we do not see instead of the surfaces in sight. This gives the basis of clear thought and of idealism.

The love of color masses may therefore be considered like ornate word expressions, an indication of physical defect. Such people have weak eyes and a shortage, not a surplus, of character. Movement aids motor dominance. An arrest of movement divides up the attention and gives to the disjustive elements of personality a chance for expression. The repressed elements in a motor personality are sex and fear. Surfaces are pleasurable that excite sex feelings or repress sensations of fear. The dominant surface associations are therefore related to either sex or safety. Rich, deep colors have a sex association, while regularity of outline gives a sense of security. Design might be defined as the art of making timid people feel safe. This end is accomplished by the endless repetition of some elementary figure. If on approaching a building the observer sees a mass of accurate details, he assumes that the floors have been carefully constructed and that the elevator has been recently inspected. Domes always give the same sense of relief. A building with no visible roof gives to timid people a feeling of instability. Regular fences likewise arouse a feeling of safety. Banks seem to remove the fear of their depositors by supplying a multitude of bars and posts, ostensibly to protect the deposits; but any observant person realizes that the real protection lies in the vaults and not in these shams.

As I was walking by Columbia University with one of its professors, he said, "Look at that fence. Is not it beautiful?" "Yes," I replied, "the chickens are safe. But you should remember that farmers now guard their property from sneak thieves by barb wire. Some generations hence your successor will be making the same exclamation you are making, as he gazes at the imitation barb-wire fence which will then surround Columbia." Was he artistic, or was I?

The same question of natural artistic appreciation arises when a person from a flat country compares his ideas of beauty with the inhabitant of a mountainous region. I was reared in a part of the West so flat that measurements were needed to find which way the water would run. There were no domed hills to evoke the feeling of safety, or wooded backgrounds to furnish protection from the unknown beyond. The sweep of the eye reached to eternity; parallel lines came together in the dim distance. Such a picture—all lines and no surfaces—makes

the beholder think not of the present reality, but of its unseen complement. The sensualist of the wooded mountains divides the real into its parts, gets beauty out of the contrasted zones and is satisfied. The idealist blends the real into one unit and creates for himself a complement out of the unseen. Beauty is thus a relation between the seen, contrasting element with element, or it is the force that drives the beholder from the seen to the hidden background.

When I came into contact with conventional art, it took me a long time to see what made it attractive. I disliked the contrasted surfaces and the obtrusiveness of its sex and safety associations. New pictures gave me pleasure, because they evoked in me a realization of the beyond. Sculpture was even more satisfying, because the absence of a background forces the artist to rely for his effect wholly on lines, instead of on contrasted surfaces.

Furniture also has its motor and sensory effects. A chair elaborately designed makes one think of the pleasure of sitting in it; a chair with lines arouses the thought of some one you would like to have in it. A table with surfaces makes the beholder think of gorging the richly-colored food that should be on it. A table in which lines dominate arouses the thought of company and serious conversation. Lines bring in the absent. Surfaces eject from their folds a rich content. The bareness of the one and the completeness of the other give beauty.

The essence of my position is the conflict of the motor powers with the earlier formed sex and sensory centers. Adjustment at adolescence is motor; disadjustment is sexual and sensory. The normal child fights its way into motor dominance and by the struggle makes its character. The abnormal remain under sex and sensory control. This would be readily admitted in cases where the abnormalities are so marked as to unbalance the mind. The milder cases, where sex and sensory impressions exert a disjustive pressure, are viewed as natural traits. Those who exhibit them are often regarded as superior to those with complete motor control. The real test of a natural trait is its tendency to strengthen the personality of its possessor. Evolution creates unity of control. Mechanisms for *expression* are organic: mechanisms for *repression* are due to the association of ideas, and hence postnatal in origin. There are no organic repressions. They all have a social origin.

In the case of a child all repression is bad. Conscious morality should begin with maturity, and then should be a relative pressure, not an absolute prohibition. The child should be protected by an environment that prevents the formation of premature sensory associations. A man with a strong personality would result. With the change would come a simpler language and a morality that evokes character. The longer childhood and the delayed education bring compensation in a longer working period and in new forms of social activity from which would come a better art, a higher morality and a purer religion.

THE SEQUENCE OF SCIENCES IN THE HIGH SCHOOL

By JOSIAH MAIN

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OF all the questions to which educational committees and journals have been devoted, the problem of what the high school sciences shall be, and the order in which they shall be given, shows least progress toward final agreement. The two phases, what they shall be, and where each shall go, are so related that they can not be considered separately, for while we are fixing the one, we find that we have forced the other out of place. The problem is complicated by the introduction of a third unknown factor of how the sciences shall be affected by the introduction into the high school of industrial subjects, such as agriculture, which includes many applications of science. And it should be stated that no debate of this subject can be very profitable that does not include in the premises an agreement as to what sciences should be undertaken below the high school.

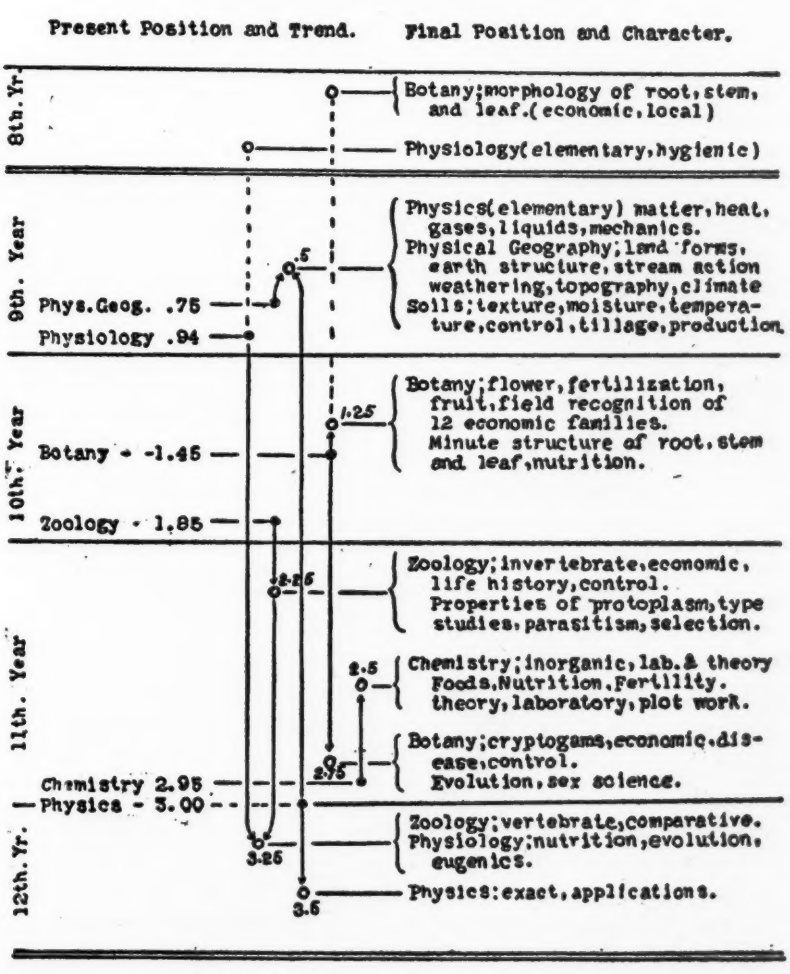
High school mathematics has a logical sequence that admits of little variation. History has a chronological sequence which must be observed, at least within its larger units; and literature has a genetic sequence which finds its counterpart in the development of the child. The science group, on the contrary, is split into distinct sciences, each of which in the hands of its specialist and advocate contends for the place of vantage in the latter part of the course, where all the others may contribute to its dignity by preparing its way and making straight its paths. Thus, for example, botany and chemistry are each politely saying to the other, "after you." Meanwhile the result of this internal disagreement is to break the unity of science, thus greatly impairing the value of each division, while weakening the ability of the whole group to properly assert itself in the larger claims of the several groups.

The "unity of science" implies a dependence between different sciences which will usually be found to be mutual and argues equally well forward or backward. One method of compromising conflicting claims for precedence is to divide a science into two portions, the elementary to be given in the first year, or earlier, as an introductory science, and the advanced phase placed in the last year of the course. This method is specially suited to such a science as physics, whose rapid growth in recent years has accumulated more subject-matter than the average high school can properly treat in a year. Such a proposition is suggested

in the report adopted by the secondary department of the National Education Association in July, 1911, on "The Articulation of High School and College." In its report of 1893, the Committee of Ten suggested a similar treatment of the subject of geography, a recommendation that seems to have had little influence on subsequent practise.

Despite the variety of opinion as to what the sequence of high

Sequence of High School Sciences.



school science should be, experience has established a generally accepted order, agreeing more or less with the authoritative report of the Committee of Ten. Recent high school courses of study of the twenty-one largest cities in Illinois, omitting Chicago and its environs, give interesting data concerning the present practise. The method of using these data was to give the value .5 to a science offered any time in the first

year, 1.5 if offered in the second, 2.5 in the third and 3.5 in the fourth year. For each subject, the value was taken as determined by the printed course, and the sum of the twenty-one values divided by twenty-one to find the average. Thus should each offer a particular science in the first year, the average would be a value of .5; but should any offer it at a later date the effect would be to raise that value an amount agreeable to the year in which found, subject to the reduction due to averaging. The averages thus obtained for the six sciences susceptible to this treatment were as follows:

Physical geography	.75	Zoology	1.85
Physiology	.94	Chemistry	2.95
Botany	1.45	Physics	3.00

The order given in the table is the prevailing order in these schools, the chief value of the table being to show the relative, rather than the actual positions. For it is apparent that the natural tendency to vary is restricted within the limits 0 and 4, the beginning and close of the high school course, with the result that reducing a science from the high school into the grades inequitably destroys its influence on the average, and that intermediate values may result from averaging extremes as well as means, while all averages tend unduly toward the middle value.

The figures should also be interpreted in the light of a statute requiring physiology to be taught in the first year of the high school, and another which requires geography and physiology of all candidates for teachers' certificates, all the remaining sciences but chemistry being required for the first grade certificate.

In an investigation of 48 high schools "principally in the Middle West," Miss Ada L. Weckel[1] obtained data which give almost the same sequence, though not the same values for these subjects, the only difference being that physiology, probably because it is not so firmly bound in place by statute in other states as in Illinois, has migrated to a position between botany and zoology. Mr. E. E. Ramsey[2] in a similar investigation of the high schools of Indiana and other states of the Middle West gets corroborative results.

The recommendation of the Committee of Ten concerning geography was that the more elementary portions constitute the "physical geography" of the first year, while the more technical portions be carried over to the last of the course. Though no school was found to divide the subject for an elementary and an advanced treatment they generally agree with the recommendation by placing it in the first

[1] *School Science*, May, 1911.
[2] *School Science*, December, 1911.

year, variations from which showed a tendency to carry it over to the last year.

No recommendation of the committee has been more generally observed in practise than the one placing botany and zoology in the second year. However, these two subjects, at first closely associated, show an unmistakable drift from their moorings, botany moving downward toward the first year, as shown in Miss Weckel's investigations, and zoology moving toward the third year or being eliminated. Botany is subjected to two opposing influences, which will probably divide it into two distinct portions.. The introduction of agriculture below the high school is already resulting in the injection of much elementary botany into the elementary grades, while the leading botanists insist on giving high school botany a character that would move it in the other direction. The migration of zoology to the third and fourth years, to be followed by physiology, as located by the Committee of Ten, would make possible an evolutionary treatment of the combined subject that is much to be desired.

The recommendation of the committee regarding physics and chemistry has not been respected. It will be recalled that the conference to whom the committee assigned those subjects recommended a placement identical with the one now prevailing; but owing to their division of physical geography into an elementary and an advanced portion, the committee reversed that order so that physics might precede and prepare for the advanced work in physical geography. The reason for this reversal not proving well founded, the recommendation of the conference should prevail. This would agree with the present evident tendency to relieve the physics difficulty by putting its elementary phases into a first-year science course and leaving the more technical and quantitative treatment for the last year of the course.

The proverbial inertia of school curricula makes unsafe any *laissez faire* method of establishing the sequence of high school sciences. But it must not be thought that the present sequence is to any considerable extent the result of neglect. What then are the influences that have established this order of treatment?

Doubtless authoritative recommendation of competent committees have been a strong influence. Also, the accrediting system of the colleges and universities, by requiring a certain character of work offered in admission, have indirectly determined its location in the course. And an increasing complexity and supposed dependence of subjects has been a component of the final result. The tendency to place general and prescribed courses before special and elective courses has been a strong influence. Other temporary causes are the supply and demand of scholarship in high school teachers and their preparation for the

different sciences, and the relative expense of equipment which the different sciences demand. Finally to be mentioned as a powerful factor is the recency of introduction of the various sciences to the course. All subjects shown in the high school course have entered it from above, having been handed down from the colleges, and tend to gravitate from the latter part of the course toward the earlier, until they find their supposed level in youthful capacity. Thus chemistry, the most recent introduction, has probably not yet exhausted its downward tendency.

Yet the foregoing influences are all more or less superficial and transient. Deeper than them all is a rational motive that has sometimes found its expression through them and should ultimately control the sequence of science in the high school.

With the young the learning process involves a great deal of muscular reaction. This necessity of motor expression diminishes with advancing years and the accumulation of an interpretive stock of motor experience with things. The size of the muscles involved in these reactions is an index of the stage of development of the learner. And since the accuracy and promptness of every muscle seem capable of unlimited improvement by education, they, too, indicate stages of development. On final analysis, the correct gradation and sequence of all rational school subjects will probably be found to conform to muscular development. The difficulties in high school sciences mostly inhere in the formulæ with which the teacher short-circuits his explanations or the verbiage with which he covers his ignorance. Whatever is definite is easy. Uncertain or confused things, only, are difficult and anything worth knowing may be taught the adolescent by a competent teacher.

Applying this test of motor adjustments, a solution of the problem of high school science will at the same time determine the correct sequence of the different phases of agriculture in the schools. All of the subjects involve the use of both the large and the small muscles. Subjects demanding more use of the finer muscles go later in the course than those involving more use of the coarser. Those requiring skill and accuracy of the larger muscles may often have an early or late treatment, or both. First-year high school students are familiar with or may make all of the adjustments demanded by such work as geography, soils, stream action, farm machines and elementary physics. Tillage, the study of the corn plant and ear, the morphology of root, stem and leaf, and budding, grafting, pruning and spraying involve motor adjustments appropriate to the grammar grades. The examination of cells, fibro-vascular bundles, and the stamens and pistils of most plants, and the making of biological drawings, work which exercises the finer muscles of accommodation, the preparation of slides and the

adjustment of the microscope, do not belong below the second year of the high school. And correlated with the botany may appropriately be placed budding, grafting, spraying and pruning in a more rational form and demanding a higher grade of skill. School gardening, exercising, as the work does, the larger body muscles, is appropriate to the primary grades. Nature study may be defined as the most appropriate muscle culture known to the schools in that it automatically adjusts itself to the stage of development of the pupil. Until some one defines more definitely than has yet been done the character of animal husbandry best suited to the schools that subject may go anywhere in the course. When the need and the opportunity for the drawing of correct animal conformation are appreciated, it will be given an advanced position. Exercises in advanced physics demand delicate adjustments appropriate to the last year of the high school course, which position also agrees with the mathematical requirements of the subject. Accurate use of dissecting instruments, the fine balance, fragile glassware and c.p. reagents, and the making of a pure culture and keeping it pure, demand muscular skill not to be found below the third year of the high school course.

Influenced by this factor, the high school sciences will find their places, and the sequence of the different phases of agriculture that are naturally correlated with them will, by the same process, have their positions determined.

THE RELATION OF CULTURE TO ENVIRONMENT FROM THE STANDPOINT OF INVENTION

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THE relation between man's life and the physical make-up of the earth has always been a serious problem. In our schools we often hear the doctrine that geography is nothing more than the study of peoples in their adjustment to the particular part of the earth they inhabit. This emanates from the teachings of the great German geographers Humboldt and Ritter, to whom the physical features of the earth were the determining factors in the distribution of life. Later Ratzel took up the problem from a strictly human or anthropological point of view and gave us the term anthropo-geography. The rapid development of anthropology during the past twenty years, and especially its recent trend toward a cultural point of view, has again brought to the front this question of relationship between human activities and physical geography. To anthropology the problem becomes rather fundamental, and while not by any means so inclusive as it must be to anthropo-geography, which must depend upon the truth of the assumption for its existence, is nevertheless one whose solution is a matter of some consequence. Thus the question of culture and environment becomes the common concern of at least two sciences, geography and anthropology.

A full discussion of the subject would take us over the whole field of geography and anthropology; hence, we may here consider but a few points. As a rule, those who discuss this problem know a great deal more of geography than they do of anthropology and indeed it is but recently that we had at hand anything like a complete collection of data on the culture of even one non-historic group of people. As field-anthropologists are now industriously increasing our knowledge of such peoples, it may not be out of place to discuss the general problem from the standpoint of these data.

In such discussions it is convenient to make a provisional distinction between cultural phenomena and biological phenomena and the most convenient is that based upon heredity. The strictly anatomical characters, physiological and psychological functions are innate, while culture is not innate but acquired by the individual during life by imitative or educative processes. We can thus set over on one side man's biological equipment, his bodily functions, mental characters, instincts, etc., as against or in contrast to the cultural characters, or products of these activities in social life.

The biologists have given us some idea of the kind of physiological equipment man is born with and the psychologists have made some progress in the description of the psychological equipment, all of which is no doubt familiar to the well-educated. On the other hand, the development of anthropology has been so rapid and the points of view so illy formulated that a few remarks as to the character of culture seem necessary. On one point all students are agreed, viz.: that it is the functioning of the psychic part of man that produces culture. When it comes to assigning cultural phenomena to specific psychic activities there is some difference of opinion, but for the most part it is recognized that since culture is not inherited it must be a construct and as such is largely the work of the intelligence. For a long time many psychologists and sociologists have seen in this distinction one of their most important problems. To them it appears that social progress or cultural change of any kind is in last analysis the production or creation of something by the psychic activities of individuals, which process has been regarded as invention. In practical life we are accustomed to apply this term to ingenious mechanical devices, but in fact anything produced by our psychic activities, whether it be a new game, a word, a picture, a song, etc., is the same kind of thing and one to which the term may be applied. Any such invention taken up by a social group of people becomes thereby a trait of culture.

Culture as anthropologists use that term is a complex of elements as varied as those making up our own lives. Most geographers, however, give their attention almost exclusively to the economic aspects of culture, or to those traits listed in anthropological literature under the head of material culture. This, no doubt, comes about because it is in these phases of life that culture and geography are in most direct contact; language, religion, literature, art, family organization, etc., are less articulated with geographical phenomena, but geographers are quite given to sweeping them all into the economic category and claiming the most intimate contact throughout. It is clear, however, that the primary problem is to be found in the relation between man's material culture and the earth, which for convenience we shall designate as the environment. Our question then becomes as to what kind of a relation exists between material traits and environmental characters.

Material traits, such as methods of preparing food, the manufacture and use of tools, the methods of the chase, weaving, pottery, etc., are clearly inventions, and if the environment has anything like a determining or a causal rôle in the making of culture, such must be manifest in the inventive processes themselves. Our problem here is complicated by the existence of two stages or steps. In the first place some individual must develop the idea and demonstrate it; then it must be taken up by others and become more or less common to the social group. The

invention, however, remains such regardless of its fate at the hands of social selection. Yet we must consider several possibilities since it is conceivable that the environment might be the determining factor in the selection alone, leaving the individual free to invent as he choose. Hence, our discussion falls under two heads: (*a*) The relation of the environment to invention; (*b*) to the selection, or socialization of inventions.

One of the fundamental problems in the investigation of invention has been the determination of what the process really is. It is in a way a creative process, but it must have something to work upon; it can not make something of nothing. We need not, however, distress ourselves with the puzzle as to whether there can ever be a distinctly new idea, for an invention in the cultural sense is a new relation assumed or observed between old experiences rather than an experience itself. When the geographers claim that all concrete experiences involved in such an invention must come from the environment, they are on indisputable ground. Thus it is undoubtedly due to the presence of snow that the Eskimo invented the snow house and to experience with birchbark that the Eastern Woodland Indians devised the bark-covered tipi. The real problem is as to whether there is anything in the very nature of birchbark as a part of the environment that necessitates the invention of a certain peculiar kind of house. Unless one holds to an ancient belief, he must assuredly say that there is no such necessity. It is true that a person who never experienced birchbark directly or by hearsay could not have made the invention, and if he had, it could not have passed into practise unless the material was made available by the environment. Thus it is clear that the environment furnishes the materials from which inventions are made and which thereby enter into the so-called material cultures of peoples. But the essential thing in an invention is the relation between experiences. In the case of birchbark the relation between bark experience and house-building experience can have no existence outside of the psychic life of man, the environment can lay no claim to it. Its production must emanate from the human mind and not from the earth. It seems, therefore, that we have here an answer to our query, for by the nature of the inventive process the determining factor is found in mental activity. Environment furnishes the materials and in that sense only limits invention. To invent a birchbark-covered house a man must have lived among birch trees, but the mere living there does not require such an invention.

We have noted that an invention becomes a cultural trait when taken up by many individuals. In this case the relation is handed on and on by education and imitation and so cultural traits are after all based upon a recognized relation between experiences. The causes that lead to the adoption or rejection of an invention must be recognized as the

chief factors in the determination of culture, but we must note that they are selective only and not real producers of new things. As in the previous discussion our quest for the producer ends at the threshold of the inventive process. In this case, however, we start not with the unrelated experiences, but with the invention already made and offered to society.

Many of the factors entering into the choice of society are familiar to the general reader, for in sociological literature will be found lengthy discussions of prejudice, tradition, the function of the genius, etc. These, it will be observed, are social, or human factors, and are not due to the environment. Yet when we take material culture alone it must be recognized that with respect to it these social forces are less active. The experience of the world is that while a savage will throw away a stone knife and substitute a steel one after the first trial, he will be very slow to change a religious practise and especially a social custom. We may expect then greater opportunities for the socialization of material inventions and that industrial progress will be more rapid. But there is a fallacy here, for while it is true that a savage will quickly substitute a steel knife, it will be otherwise if one of his tribe attempts to develop the manufacture of knives, or even engages in extensive trade with knives, for then at once there will be a conflict with social customs. Nevertheless, it is probably true that most improvements in weapons, tools, etc., will, when demonstrated by the inventor, find little resistance and in most cases positive encouragement. The criterion would then be the usefulness of the new invention. Thus to a roving people a birchbark house might be an improvement, provided birchbark was readily attainable or transportable. Here the environment appears as a selective factor because the adoption of any particular set of traits appears finally as an adjustment between the community and the environment. But, as such, the environment is a passive factor, for the inventions that happen to fit sufficiently well to survive pass into the cultural complex, while the others fall by the wayside. And, after all, we must not forget that the fitness of an invention is a matter of judgment and that many a maladjustment to the environment passes as the superior trait because of an error in social judgment. It is truly surprising how ill-fitting the adjustments may be and still give men time and strength to maintain family, religious and political organizations of considerable complexity. We see then that while an invention must work to survive, there is no guarantee that it will be given a fair trial and be allowed to stand according to its deserts. Its fitness is chiefly a matter of social belief, and as such subject to all the ills and vagaries of folk thought.

In general it seems that the tendency of some geographers is to lay very great stress on the part played by the environment in the develop-

ment of culture. Because they see how the environment sets limitations to human culture, or inventions, they sometimes assert that in it are to be found the causes producing cultures. A more acceptable view seems to be that which recognizes the province of the environment in deciding as to what may not become a part of human experience, but that among the experiences it makes possible is a wide range, in fact almost infinite range, of yet to be discovered relationships among which are many that may enter into the culture of the future, if both the man and the hour come. If in the discussion of this question we do not lose sight of the inventive nature of the processes producing material cultures and the curious psychic origin of the underlying relationship of ideas, on the one hand, and the passive limiting character of the geographical environment on the other, we shall not be led far astray. It is natural that in the study of geography emphasis should be given to the physical, faunistic and floral characters of the environment, but this should not warrant the assumption that these characters will in themselves be a sufficient explanation of the cultural differences observed among the peoples of the earth. It is also to be expected that anthropologists will overweight the value of the psychic factor in the formation of cultures because they deal in the main with such phenomena, but they in turn must not ignore the limiting character of the environment. The value of such discussions as this can only consist in holding each group of investigators to the proper recognition of the relations between their respective fields. Environment *vs.* culture may never cease to be the debatable ground over which the opposing parties struggle with varying fortunes, but we believe that a little analysis of the phenomena will reveal the chief factors, make evident their relative values and so lead to saner views.

THE FUTURE OF THE NORTH AMERICAN FAUNA

By the late WALTER L. HAHN, Ph.D.

THAT the animal life of North America is changing is a statement requiring no proof. Every one knows that deer, elk, moose, wolves, bison and many other animals are no longer found in places where they were once numerous. Nearly every one also knows that some pests, such as rats and mice and several noxious insects, have been brought to this country from Europe, while the potato beetle and some other species, natives of North America, have multiplied and extended their range.

It is impossible, within the limits of this paper, to specify all the changes that have taken place and are now in progress. Hence it will be my aim to point out certain general tendencies, and certain general influences at work upon our fauna, the word fauna being a somewhat technical term used to designate the sum total of the animal life, great and small, in any circumscribed region.

If asked why the great game animals have disappeared from certain regions, most people would doubtless say, "Indiscriminate slaughter has exterminated them." This answer is undoubtedly correct as far as it goes. For a full explanation of all of the changes that have taken place in our fauna we must seek deeper reasons. Why has not "indiscriminate slaughter" exterminated the mice and rats and other noxious creatures against which we have waged ceaseless war for many generations? In other words, what are the biological and physical conditions that determine whether an animal species shall survive or perish in modern America?

A living organism, even the simplest, is a thing of vastly greater complexity than any mere chemical compound or any physical law. We know how to kill individual organisms, but frequently we do not know what will exterminate a species. If a lion and a lamb lie down together, we know which will be on the inside. But if a given number of lions and a given number of lambs inhabit a great area we can not predict the exact results; and this illustrates the futility of trying to make a definite analysis of the future of any particular species.

I shall now consider the future of North American animals from the general standpoints of size, habitat, relation to man, fecundity, mental traits, and finally give a few interesting facts not comprehended in the above classification.

Size

Size is the most obvious characteristic possessed by an animal. Whether we are naturalists or sportsmen, or neither, we instinctively classify all animals as large or small. Likewise there is nothing about our fauna so obvious as the fact that the larger animals are disappearing. The bison is gone, except for a few small and protected herds. The elk, moose, caribou, mountain sheep, antelope, cougar and grizzly and black bears are gone, except in sparsely settled regions. On the other hand, rodent pests swarm throughout every city, and the field mice, ground squirrels, cabbage butterflies, house-flies and hosts of other small insects continue to make trouble for the agriculturist.

Large size increases the value of an animal whose products are useful and hence makes it more desirable game for the pioneer who hunts to supply his larder and also for the sportsman who hunts for the sake of trophies. Large size also makes an animal apparently more dangerous if it has rapacious habits. I say *apparently,* for the microscopic *bacillus tuberculosis* kills more people in North America every year than all the beasts of prey have killed on the same continent since Columbus first sighted San Salvador, while the house-fly, disseminating the germs of typhoid fever and kindred diseases, is more deadly than all the wolves, panthers and rattlesnakes.

Sometimes we find related species having the same habits and living in the same region, but differing in size. Invariably the larger species is more sought after and diminishes more rapidly than the smaller. Squirrels illustrate this statement very well. In the northeastern United States three species of tree squirrels were once abundant. All had very similar habits, and ate practically the same kind of food. The fox squirrel and the gray squirrel are now on the verge of extinction in many places, while their smaller relative, the little red squirrel, thrives. Likewise the coyote fares better in contact with civilization than does the wolf, and the cottontail rabbits thrive where the larger jack rabbits and snowshoe hares are being exterminated.

Eight species of woodpeckers were once abundant in the forests all over the eastern states. Six of these are still common while the two largest species are extinct except in a few inaccessible swamps.

Large size means great strength. In the past this has been an advantage, within certain limits, by making an animal invincible to the attack of other animals. It is of no avail in stopping bullets, and hence is a disadvantage to a species that must count civilized man as one of its enemies.

The animals of the future, not only in North America but the world over, will have a smaller average size, and most large species will cease to exist unless they are domesticated.

Habitat

Some animals live, either by preference or necessity, in the forest; some live in meadows or prairies; some prefer uplands and some swamps; others must live in the water. A few are adapted to life in a variety of situations.

By far the greater part of North America east of the Mississippi River was at one time forest clad. The trees have been cleared away from this region until now they are limited to scattered tracts a fraction of a square mile in area with a few larger forests still more widely separated.

The species that live chiefly in the forest include among the larger kinds elk, moose, caribou, Virginia and western black-tailed deer, and black and grizzly bears. Smaller forest-dwelling species include several kinds of lynxes, the fisher, marten, Canada porcupine, several species of squirrels, as well as many birds, snakes and lesser animals. Species that live habitually in the open include the bison, antelope, coyote, jack rabbit, prairie dog, many kinds of mice, birds, snakes and smaller creatures. Among the species that get along equally well in the forest and open country, we may notice the red fox, certain mice and birds, woodchuck and chipmunk and there are many others.

It will require no argument to show that all of the forest-inhabiting species I have named are diminishing and if space permitted this could be shown for nearly every forest-loving species concerning which we have the data to form an opinion.

Turning to the plains species, we find the bison and antelope have diminished because of their large size, economic value and gregarious habits. The jack rabbit is also diminishing in regions thickly settled and the prairie dog has been found so destructive that measures have been systematically undertaken to exterminate it.

The animals mentioned above, although the most conspicuous ones of the prairies, comprise only a fraction of one per cent. of the fauna of that region, and when we consider the remainder we find many animals that, if not everywhere increasing, are at least extending their range. There is abundant proof that the "cotton-tail" rabbit of the prairies, which is a different species from that of the Atlantic Coast states, has in recent times extended its range eastward to Ontario and western New York. Some of the native field mice and ground-squirrels are working eastward.

The Harris sparrow, a typical bird of the western prairies, was reported from Indiana a few years ago for the first time. The Dickcissel, field sparrow, chipping sparrow and many others have certainly become more widely distributed in the central states than they were half a century ago. Some of the meadow butterflies are becoming more

numerous in the same region and there is some reason to think that certain fishes are spreading eastward across Illinois and Indiana, the border states of the prairie region. Just how general this eastward migration may be among the various classes we do not know, but a reason for it is not difficult to find. Clearing the forests has brought about conditions somewhat similar to those of the prairies, and the small species that can exist in the pastures, meadows and roadsides now find congenial surroundings farther east, and in the east competition is less severe than it was formerly because the forest fauna has diminished.

In this connection it is worthy of note that there is also a slight but rather general tendency of our fauna to migrate northward. This may be the latter end of a general northward migration begun some thousands of years ago when the great ice sheet that then covered most of northeastern North America began to retreat. There were few, if any, animals in the region at that time, but, as the ice melted, and the climate became warmer, the region was again occupied by a fauna migrating into it from the south. At present this migration is not rapid enough to be of much importance.

In my brief enumeration above I mentioned several species that seem to do equally well in wooded or treeless regions. These are the species that are fitted *par excellence* to survive, and, barring some that are ill adapted because of special modifications, they are the ones that are holding and will continue to hold their own in point of numbers.

Animals inhabiting fresh water are beavers, muskrats, ducks, geese, snipe, frogs, fishes, mussels, crayfishes and a host of other animals, small in size but numberless in individuals.

What is the tendency among these animals? To answer this question we must consider the physical changes in the bodies of water. Swamps have been drained and their bottoms converted into gardens and cultivated fields. River courses are straightened and the waters confined within their banks. Sewage and refuse dumped into streams pollute their waters, and sometimes wipe out the fauna completely, and always injure the larger species. Forests are cleared away, with the result that streams, once dotted with placid pools, now become raging torrents at one season and dry channels at another.

Such changes can not fail to have a disastrous effect on all classes of aquatic animals. The diminution of waterfowl, food and game fishes, muskrat and beaver, which is the result, is too well known to need comment; the decrease of small animals is almost as great.

It may be argued that the work of drainage is counterbalanced by the digging of canals and the building of reservoirs for irrigation. There is no question but that building great reservoirs in arid regions will somewhat increase the aquatic fauna of the surrounding districts. But the isolation of these bodies of water and the obstructions in their

outlets will preclude any general immigration to their waters; and their fauna, for the most part, will be restricted to minute animals, insects and food fishes artifically introduced.

It can be asserted with certainty that there is a general tendency for aquatic animals to disappear.

Relation to Man

At first thought we might assume that useful species will survive and injurious ones will be wiped out, since man is the all-powerful lord of creation. But the most useful animals are the ones that disappear first. This is because of the unfortunate fact that man is a selfish being and thinks more of the satisfaction of his immediate desires than of the good of his race. Fortunately for the animals concerned, we are waking up to their value and many useful species are now reared in small numbers in a state of semi-domestication and there is a possibility that deer, foxes and many other animals valuable for food or fur will some day be fully domesticated.

On the other hand, it is true that injurious habits tend to bring about the extermination of a species. The venomous snakes are eminently fitted for protection from natural enemies. Their deadly nature has caused man to war upon them and in some localities his warfare has met with so much success that the once dreaded copperhead and rattlesnake are now extinct. The fear in which the pioneers held panthers, wolves, lynxes and other beasts of prey, played a large part in their early extermination.

Fecundity

There is another group of noxious animals against which man rages in impotent wrath. These are the mice and rats, the potato beetles, scale insects, flies and various other injurious insects. Among all of these creatures small size plays an extremely important rôle in the protection of the species. If a mouse weighed 100 pounds instead of less than an ounce, it would be more easily found and killed. The yet smaller size of insects makes them even more difficult to cope with.

Of much greater importance than their small size is the fecundity of these pests. A female deer produces no offspring until three years old and then only one or two a year. The other large animals produce young at about the same rate. But a female rat begins to bear young when six or eight months old and may produce 50 or even more in a single year. A house-fly, under the most favorable conditions, may lay eggs within two weeks of the time the egg was laid from which she herself hatched.

A single pair of flies, warmed to activity in April, have within themselves the potentiality of producing before October (if every egg laid

by them and their descendants should hatch into a maggot that would mature into a fly) at their normal rate of increase under favorable conditions, about one hundred trillions of flies, at a conservative estimate, or fifteen millions of tons, by weight.

Of course many flies fail to reach maturity and only a small percentage of the eggs laid ever hatch. This statement has been introduced here merely to show how ineffectual is our warfare against animals procreating their kind at such a rapid rate, as contrasted with the effect of slaughtering a few slow breeding animals. Yet many of the microscopic organisms, both harmless and disease-producing kinds, multiply infinitely faster than the house-fly.

Down to the present generation, a rapid rate of reproduction has been the surest means possessed by any animal species of withstanding the enmity of man. Now scientific knowledge is beginning to triumph over both fecundity and small size. Mosquitoes have been exterminated by the wholesale in the canal zone. Europe, Asia, Africa and Australia have been successfully ransacked to find natural enemies that will hold in check scale insects, and codling and gipsy moths. A partially successful attempt has been made to inoculate rats with a disease that will kill them as cholera once killed men. War is being successfully waged on the germs of tuberculosis, yellow fever and many other diseases, and men best qualified to judge look confidently forward to a day when not one of these infinitesimally small but infinitely baneful organisms shall exist among civilized peoples.

Mental Traits

Under this head we may group several more or less distinct kinds of traits. First, there is the gregarious instinct, the tendency to herd together so noticeable in many animals. "In union there is strength" seems to be a motto in the animal as well as the political world. By banding together into great herds the bison became invincible to all foes save man. But with the advent of civilized man, armed with breech-loading rifles, the herding instinct of the animal only made its slaughter the more easy. The same is true, to a greater or less extent, of many other animals. Colonel Roosevelt says that, "the elk is the most gregarious of the deer family," and it was also the first of its family to disappear before the advance of civilization in almost every section of the country.

In the early seventies, passenger pigeons occupied a vast breeding ground in Michigan. It is said that in many square miles of this thickly wooded area, there was not a tree without a brooding pigeon on its nest at the proper season. Pot hunters found the birds, killed them with hands and sticks and guns, packed them in barrels and shipped

them to market by the ton. Recently, in an effort to save this fine bird from extermination, a prize of one hundred dollars has been offered for the first person reporting a pair of breeding passenger pigeons.

A couple of decades before the passenger pigeon's extermination, flocks of hundreds of Carolina paroquets used to swoop down on the apple orchards of Kentucky and southern Indiana. Naturally the farmers took their guns and wreaked vengeance on the birds, and to-day the Carolina paroquet is all but extinct. And it has long been driven from the region I have just mentioned.

The economic factor was an important one in the extermination of these birds, but the rapidity of their extermination was due to the fact that they flocked together and were killed by the wholesale.

Beasts of prey are more courageous than weaker animals and all of the larger ones are gone from thickly settled communities. The rabbit is notorious for its timidity and still abounds everywhere outside of city limits. True, fecundity and small size play an important part in the preservation of the rabbit, but suppose that possessing these characteristics, the instinct of self-defense were stronger than the instinct to flee? The inevitable result would be the destruction of the race.

No mental trait has been of greater value to an animal species warred upon by man than timidity. The trait next in order of value is cunning.

The fox has always been justly considered as a type of the cunning animal, but the trait has not been equally developed in all kinds of foxes. In eastern North America there are two very distinct races, the gray fox and the red, cross and silver foxes being mere varieties of the latter. It is highly probable that the American red fox is descended from animals brought from England by gentlemen emigrating from that country during the eighteenth century, although this fact has not been clearly established. It is certain, at least, that it was either rare or absent in Ohio, Indiana and Illinois during the days when these states were frontier regions, and at that time the native gray species was abundant. Now the gray fox is extinct except in the rougher and more wooded districts, while his red relative is a pest in even the most densely settled valleys. The two species are nearly equal in size, fecundity, value of fur and destructiveness to poultry. They eat the same food, they live in the same kind of places, with the exception that the gray species seldom makes its den in the open fields, while the red often does. The vital point of difference seems to be in their cunning. The red fox, if not the sly renard of Europe, is certainly a close counterpart in cunning, while its gray cousin is lacking in this respect. In these two species, at least, the difference between survival and extermination depends upon cunning.

Miscellaneous Peculiarities

There remain to be considered certain characteristics which can not be very accurately designated by any well-understood and precise term. I refer to what is sometimes called by biologists a high degree of specialization, and more particularly specialization in the direction of bizarre and conspicuous features.

The porcupine is a good example. This animal is of absolutely no economic importance to civilized man. It lives in the forests and eats little save twigs and bark. Its flesh was eaten to some extent by Indians and its quills were prized by them as ornaments, but neither flesh nor armature are valued by whites. It might be supposed that a few porcupines could find sufficient food and shelter in any small wood lot and that they would remain there unmolested because of their inoffensive habits. Yet few species have disappeared more rapidly before the advance of civilization.

The animal had few natural enemies because of the efficient protection of its spiny armature, consequently it had no fear and was a slow breeder. Its spines, however, afford no protection from man, and there can be no doubt that more porcupines have been killed from curiosity excited by the peculiar appearance of the animals and mere wantonness than from any other reason.

One species of armadillo is found in the Unites States chiefly in Texas. It is an animal with a head and body about a foot in length and a tapering tail of equal length. Its body is covered with an armor of bony plates, quite solidly joined together in most places, but with overlapping joints in the middle. When attacked it curls up, covering the poorly protected belly, throat and nose with its tail, and hence becoming invulnerable to teeth and claws. It is harmless in habit, living chiefly on insects. Its peculiar appearance frequently leads people to kill it from no motive except curiosity and wanton love of slaughter. Recently a tourist trade has grown up in the armor, which is made into a basket, the tip of the tail being brought forward to the neck and fastened there to form the basket handle. Thus an economic relation is growing out of the bizarre appearance of the animal and its extermination seems to be only a matter of a few years, unless it receives better protection.

Horned toads, lizards and, to some extent, tortoises and snakes are being slowly exterminated because their appearance arouses the desire to kill and not because of any economic motive. A few comparatively harmless species of insects, namely, the walking stick or devil's darning needle, the praying mantis or rear-horse, and the rhinoceros beetle have been nearly exterminated in some parts of the country merely because their unusual appearance arouses an interest in them and their life is forfeited therefor.

We might also include in this category the snowy heron, the roseate spoonbill and other birds that have been slaughtered for their plumage. Although the economic value is here the direct motive for the slaughter, this value grows out of unusual (and beautiful) modification of the plumage.

The preceding paragraphs are necessarily sketchy, because the subject is too large to treat in detail and it is now desirable to gather up the threads.

Briefly, the general tendency of the North American fauna is toward mediocrity. Large species are giving way to small; bizarre species to commonplace. Marsh-loving and forest-loving animals disappear with the advance of civilization, and grass-loving species that are able to exist in fence rows and pastures survive. Animals that yield products of value vanish before the hand of man; likewise his enemies are destroyed unless protected by small size and great fecundity. Courage and the social instinct are at a discount and cunning and timidity at a premium.

Finally man is beginning (and only beginning) to shape the destiny of his God-given dominion "over the beasts of the field and the fowls of the air." To make this dominion an intelligent reality is the aim of present-day biological science.

THE SIZE OF ORGANISMS AND OF THEIR CONSTITUENT PARTS IN RELATION TO LONGEVITY, SENESCENCE AND REJUVENESCENCE*

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I. Body Size

BODY size is one of the most variable properties of organism; the smallest living things are probably invisible to the highest powers of the microscope, the largest are gigantic beasts weighing many tons. Within the same class, and in animals equally complex in structure, variations in size are enormous, as, for example, in the elephant and the mouse. Within the same species, where structural differences are insignificant, size differences may be very great. In some species there are great differences of size between males and females; in extreme cases males may be minute and rudimentary forms, without mouths and alimentary canals, and capable of living for only a few hours, as in certain rotifers, worms and arthropods, whereas the females are relatively large and perfect individuals capable of an extended existence.

In *Crepidula* a genus of marine gasteropod which I have studied and to which I must particularly direct your attention, I have found[1] great differences of body size in the mature individuals of different species and also in different individuals of the same species. The volume of the average adult male of *C. fornicata* is 125 times that of the average male of *C. convexa;* the volume of the female of the former species in 32 times that of the latter. In these gasteropods the males are always much smaller than the females; the volume of the average female of *C. plana* is about 15 times that of the average male. All mature animals of this genus are sedentary, and many of them live in or on dead shells which are the homes of hermit crabs. In the species *C. plana* I have found an interesting class of dwarfs; the animals of usual size live in large shells inhabited by a species of large hermit crabs (*Pagurus bernhardus*); the dwarfs live in small shells occupied by a species of little hermits (*Pagurus longicarpus*). The dwarfs are sexually mature and, unless forcibly removed, live their whole life long in the small shells, where they attain an average size only one thirteenth that of the normal forms but if the dwarfs are forcibly taken out of the

* Lecture before the Harvey Society, New York, March 7, 1913.

[1] Conklin, "Body Size and Cell Size," *Jour. Morph.*, 12, 1912.

small shells and put into larger ones they may grow up to be as large as animals of typical size. These dwarfs are, therefore, only a physiological variety, produced by environmental conditions.

What are the causes of such differences in size of animals of the same species? What explanation can be offered for the enormous difference in size between an elephant and a mouse? What are the factors generally involved in determining size?

1. There is plainly an inherited factor in all specific differences of this kind. Every species of animal and plant has a more or less characteristic body size which may be said to constitute the norm of that species. This norm may be altered to a certain extent by environmental conditions, but such possible modifications are relatively slight; no amount of environmental influence could ever make a mouse grow to the size of an elephant. The limits of body size of a race or species are as certainly inherited as are any other characteristics; their causes, whatever they may be, are intrinsic in the constitution of the germinal protoplasm.

What is the nature of this inherited factor which determines the possible size of organisms? Undoubtedly it is found in the power of growth as contrasted with limitations to growth, with the rate and duration of assimilation as contrasted with dissimilation. Increase in size may be due to mere imbibition of water, or to an actual increase in the quantity of protoplasm, and secondarily of formed products, in the body. In this discussion the latter process alone will be termed growth. As long as assimilation exceeds dissimilation organisms grow, when the one balances the other they remain unchanged in size, when dissimilation exceeds assimilation they dwindle. The large-sized *Crepidulæ* continue to grow for a much longer time than the small-sized ones. A mouse achieves its full growth after 60 days and may live approximately 60 months; an elephant continues to grow for about 24 years and may live approximately 150 years.

What it is which keeps up this process of growth so much longer in one species than in another we do not know—and as so often happens, it is precisely this which we most desire to know, for length of life as well as size of body depends primarily upon the rate and duration of assimilation. It may be that there is some peculiar secretion or enzyme which stimulates growth and varying quantities of which cause one species to continue to live and grow for a much longer time than another species; it may be that some substance is formed in the course of development which limits growth and that it appears earlier in some species than in others. Since assimilation and dissimilation are chemical processes it is very probable that the factors which determine rate and duration of growth, and consequently body size and length of life, are of a chemical nature. This is a subject upon which there has been

much speculation and but little work and to which experimental investigation might well be directed with promise of important results.

2. Another supposed factor which is not precisely hereditary nor yet strictly environmental is the size of the germ cells, of the "Ausgangszellen," from which an animal develops. Morgan[2] and Chambers[3] found that small eggs of the frog give rise to smaller tadpoles and to smaller frogs than do large eggs. Popoff[4] maintains that spermatozoa as well as ova vary in size, owing to slight inequalities of division during the genesis of these cells, and he supposes that when a large egg is fertilized by a large spermatozoon a large individual results, whereas if the sex cells are smaller than usual the individual developing from them will also be smaller. In favor of this hypothesis may be cited the fact that small eggs of *Rotifera, Phylloxera* and *Dinophilus* give rise to small and rudimentary males, whereas the larger eggs give rise to relatively large females. Within the same species, where the mode of development is the same for all individuals, egg size may be a factor in determining body size, but it is a relatively unimportant factor, since the size of an animal depends not merely upon its initial size, but chiefly upon the rate and duration of its growth. In many cases the smaller egg continues to grow for a longer period than does the larger one and in the end gives rise to a larger adult. This is strikingly shown in different species of *Crepidula,* where species with small eggs give rise to large animals and those with large eggs give rise to small animals. The large eggs produce large embryos, and the small eggs small embryos, but the latter continue to grow for a much longer period than the former and in the end give rise to animals of much larger body size than those which come from the large eggs. An egg of *C. fornicata* is about one quarter the volume of one of *C. convexa,* but the adult female of the former species is about 32 times the volume of one of the latter species, while the males of the former species are 125 times the volume of those of the latter species. Other cases of a similar sort are known and they show that in different species egg size can not be correlated with body size, and even within the same species it is a relatively unimportant factor in determining size.

3. It is well known that many extrinsic factors influence the character, rate and duration of metabolism, and consequently the size of organisms. Among these extrinsic factors I shall mention only a few which are known to be important, viz., (*a*) quantity and quality of food, (*b*) secretions of certain glands, particularly the sex glands, thymus, thyroid and hypophysis, (*c*) various chemical substances, such

[2] Morgan, "Relation between Normal and Abnormal Development, etc.," *Arch. Entw. Mech.,* 18, 1904.

[3] Chambers, "Einfluss der Eigrösse, etc.," *Arch. mik. Anat.,* 72, 1908.

[4] Popoff, "Experimentelle Zellenstudien," *Arch. Zellforschung,* 1, 1908.

as ether, alcohol, tobacco, lecithin, etc., (*d*) temperature, (*e*) oxygen, (*f*) presence or absence of waste products, (*g*) conditions of normal or abnormal stimulation and irritability. These extrinsic factors which influence growth have been studied by many investigators, but owing to lack of time I shall pass over all of them except the last named. In the case of the dwarf *Crepidulæ* which are found in the small shells with the small hermit crabs there is practically no evidence that any of the other factors except the last named, are involved in this dwarfing. These animals live in open shells on sandy sea beaches along with the giant forms; so far as I can determine, the food supply is superabundant, while the conditions of temperature, aeration and freedom from waste products are identically the same for dwarfs and giants. The only difference which I have been able to detect is the size of the shells to which the animals are attached; those which are attached to the small shells of *Nassa* or *Litorina* live and die as dwarfs, reaching only about one thirteenth the volume of those which are attached to the larger shells of *Natica;* however, if they are removed from the smaller shells and placed on the larger ones they may grow to typical size. The dwarfs, however, are continually hampered by their limited quarters; they are unable fully to expand the foot or the mantle, and they are more frequently irritated by the movements of the hermit crabs than are those in the larger shells. Under these circumstances they probably take less food than those in larger quarters, and although they become perfectly differentiated and sexually mature they are dwarfed in size. Similarly I have found that *Paramecium* confined in capillary tubes never grows nor divides, though it may live indefinitely, and although precautions may be taken to change the medium frequently and thus to remove waste products and to supply abundant food and oxygen. In such tubes *Paramecium* is continually irritated and presumably takes less food than when in unconfined spaces.

II. Body Size, Cell Size and Cell Number

Is the size of an organism due to the size of its constitutent parts, or to the number of those parts, or to both of these causes combined? Evidently different organisms differ in this regard. In many plants and lower animals the number of constituent parts is directly correlated with the body size; branches and leaves, segments and organs may increase in number indefinitely with the growth of the organism. In tapeworms and many annelids the number of segments, with their characteristic organs, increases throughout life; but in more highly differentiated forms the number of body segments and organs is constant, and does not increase in number after embryonic stages. In spite of the information occasionally conveyed by examination papers, the

number of bones or other organs in the human body does not depend upon the size of the man.

In animals in which the number of organs is constant the constituent parts of such organs may vary in number with the size of the organs. Thus in a large *Crepidula plana* the gill is composed of more than two hundred large filaments, in a dwarf it consists of only fifty or sixty small ones. The liver, sex glands and salivary glands are composed of a larger number of lobules in large animals than in small ones, and the size of each lobule is also larger. Evidently the number of such body parts, whether segments, organs, filaments or lobules, depends upon the power of growth and subdivision of each of these parts. In general the more complex any part becomes the less capable it is of subdivision, and so in all highly differentiated animals we find the body parts and organs are constant in number, though variable in size; whereas in lower animals the number of body parts as well as their individual size may vary with the size of the body as a whole.

Cells are generally recognized to be the ultimate independent units of organic structure and function; the causes of growth and differentiation, of assimilation and dissimilation, of longevity, senescence and rejuvenescence are to be looked for in cells. What is the relation of body size to cell size and cell number? A large number of investigators have studied this problem in a wide range of animals and plants, and with apparently conflicting results; nevertheless enough is now known I think to permit a general answer to this question. Just as in the case of body parts and organs, so also with cells, complexity of differentiation and power of division are generally in inverse ratio. In many animals and plants certain types of cells continue to divide throughout life, where other types cease to divide at an early age. In both plants and animals those cells which continue to divide throughout the growing period become more numerous in large organisms than in small ones, but not individually larger; on the other hand cells which cease to divide at an early stage in the life cycle become individually larger in large animals than in small ones, though in closely related forms their number may remain the same. In short, the size of cells is directly proportional to the rate and duration of growth and inversely proportional to the rate of division. It is well known that muscle cells and nerve cells cease to divide at a relatively early age, whereas epithelial and gland cells, mesenchyme, blood and sex cells continue to divide for a longer period, if not throughout life; accordingly, one would expect to find that muscle cells and nerve cells are larger in giants than in dwarfs, but that the other types of cells named would differ in number but not in size—and this is the general result reached by most of the investigators who have worked on this subject (Donaldson, Levi,

Boveri, Conklin,[5] *et al.*). In the most highly differentiated cells (*e. g.*, muscle, nerve) growth takes place independently of cell division; in less highly differentiated cells (*e. g.*, epithelium, mesenchyme) the two processes go hand in hand.

It is an important fact that growth in size and growth in complexity are separable processes, for although they are usually coincident during embryonic development they are not causally united. Just as growth in body size may, or may not, be accompanied by growth in complexity, so cell division may, or may not, be accompanied by differentiation. Cell divisions may thus be classified as differential and non-differential; the former are associated with growth in complexity as well as in size, the latter with growth in size only; the former are relatively constant in number for a given species, the latter vary in number with the size of the individual. The earlier cleavages of the egg are more generally differential than are the later ones, and within the same genus and even in related genera and phyla the number and character of differential cleavages is very constant. Thus in all annelids and mollusks, with the exception of cephalopods, the ectoderm comes from three quartets of cells which are cut off, one after another, at the animal pole of the egg, and in all cases each of these quartets gives rise to homologous regions of the larvæ of the different forms; the left posterior member of the fourth quartet (4*d*) is the mesentoblast and in all annelids and mollusks (except cephalopods) it gives rise to the mesodermal bands and to the posterior part of the intestine; and in general homologous portions of larval or adult animals come from homologous portions of the eggs of these animals through the medium of homologous differential cleavages.

On the other hand, non-differential cleavages are relatively inconstant in number, position and character; they vary greatly in number in different species, or even in different individuals of the same species, depending upon the size of the egg or embryo. Thus in different species of the genus *Crepidula* the differential cleavages are almost precisely the same in all, though the relative volumes of the eggs of different species vary from 1 to 27, but the non-differential cleavages are much more numerous in the large eggs than in the small ones. It is the fact that the earlier cleavages of eggs are so generally differential that makes possible the study of cell lineage; if such cleavages were generally non-differential they would be relatively inconstant and lacking in significance.

In animals with determinate cleavage of the egg the number and nature of the cells at any given stage of differentiation is, under normal conditions, absolutely constant for each species, and it may be a constant number even for different species of a genus, especially if the eggs

[5] Conklin, "The Organization and Cell Lineage of the Ascidian Egg," *Jour. Acad. Nat. Sci. Phila.*, 13, 1905.

of the different species do not differ greatly in size. In various ascidians (*Styela, Ciona, Molgula, Phallusia, Ascidia*) there is a close correspondence in the character and number of the cleavage cells present at corresponding stages of development, even up to advanced stages. For example in all these genera there are 118 cells present when the cup-shaped gastrula is first formed and the prospective fate of each of these cells is indicated herewith: 10 will give rise to endoderm cells, 12 to muscle cells, 16 to mesenchyme cells, 8 to chorda cells, 8 to neural plate cells, 64 to ectodermal epithelium.

At the stage when the gastrula begins to elongate there are 218 cells distributed as follows: 26 endoderm cells, 12 muscle cells, 20 mesenchyme cells, 16 chorda cells, 40 neural plate cells, 104 ectodermal epithelial cells.

Each of these cells is characteristic in position, structure, size and potency, and this is true of all species and genera of simple ascidians hitherto studied with respect to this matter.

In a number of species of small body size Martini[6,7,8] has determined that there is a high degree of constancy in the number of cells in the adult body. In the appendicularian *Fritellaria pellucida* the number of cells is constant in the following organs: 28 flattened epithelial cells of body, 446 oikoplasts (columnar epithelial cells of body), 10 large gland cells in the tail, 7 flattened epithelial cells of the pharynx, 10 large cells of the endostyle, 24 small cells of the endostyle, 4 branchial gland cells, 7 branchial cells, 6 ciliated funnel cells, 19 epithelial cells in the stomach, 10 epithelial cells in the pyloris, 17 epithelial cells in the small intestine, 12 epithelial cells in the large intestine, 6 or 7 epithelial cells in the rectum, 39 cells in the brain, 25 cells in the chief caudal ganglion, 23 cells in the remaining nerve cord, 8 nuclei in heart and pericardium, 20 muscle cells, 12 large chorda cells, 4 small chorda cells.

In different individuals of this species there is a high degree of constancy in the number of these cells, the only variation being in the occasional presence or absence of a single subdivision of a cell.

Also in the rotifer *Hydatina senta* he finds that there are all together just 959 cells, or rather nuclei, in the entire body of the adult, and that each organ consists of a perfectly characteristic number of cells. Even in different species of rotifers the number of cells in many homologous organs is the same; thus there are generally 6 cells in the anterior part

[6] Martini, "Die Konstanz histologische Elemente bei Nematoden, etc.," *Verh. Anat. Gesell.*, 22, 1908.

[7] "Darwinismus und Zellkonstanz," *Sitz. u. Abh. naturforsch. Gesell. Rostock*, 1, 1909.

[8] "Studien über die Konstanz histologischer Elemente," I., II., III., *Zeit. wiss. Zool.*, 92, 94, 1909; 102, 1912.

of the œsophagus, 6 pairs of cells in the excretory tubules, and 13 cells in the cingulum, one of which is on the dorsal mid line.

In the nematode *Ascaris megalocephala* Goldschmidt[9] found 162 cells in the nervous system, while Martini[6] finds 65 muscle cells in *Oxyuris,* and 87 muscle cells in *Sclerostoma,* the latter being derived from 65 cells of an earlier stage.

A similar constancy of cell number has been found by Woltereck[10] in *Polygordius* larvæ, by Apathy in the central nervous system of *Hirudinea,* by Gaule and Donaldson[11] in spinal ganglia of frogs, and by many investigators in small but highly differentiated parts, such as the ommatidia of compound eyes, the lens fibers of vertebrate eyes, the nurse cells of certain arthropod and annelid ova, etc. Such cases of cell constancy are, as Martini remarks, "the crowning fact of determinate development." In all such cases the definite number of cells in the entire body or in a particular organ must be determined by a definite number of cell divisions which proceed from the egg, or from the protoblast of the organ, and this limitation in the number of cell divisions must in some way be determined by heredity. Since increase of differentiation is associated with decrease of cell division, the latter being stopped altogether when differentiation has reached a certain stage, it seems probable that all cases of cell constancy are due to constancy of differentiation.

Where the number of cells in an organ or in an animal is very large it is not possible to prove that the cell number is constant, but in many cases where cell division ceases in embryonic stages the cell number is constant. In such cases cell division does not continue after differentiation is complete, though cell growth does. To all such cases in which there is cell constancy Martini gives the name "Eutelie."

On the other hand, there are many animals in which the number of cells in any particular organ is not constant but is proportional to the size of the organ. In *Crepidula* the number of egg cells within the ovary and the number laid in any season varies with the size of the animal, but the size of individual eggs remains constant for each species; the same is also true of epithelial cells, gland cells and blood cells. The divisions by which such cells are formed are in general non-differential, and since both growth and division in such cases continue throughout life the size of any given type of cell is fairly uniform whatever the body size may be. In differential cell divisions, or in highly differentiated

[9] Goldschmidt, "Das Nervensystem von Ascaris, etc.," *Zeit. wiss. Zool.,* 90, 1908.

[10] Woltereck, "Beiträge zur praktischen Analyse der Polygordiusentwicklung," *Arch. Entw. Mech.,* 18, 1904.

[11] Donaldson, "The Growth of the Brain," Scribners, New York, 1895.

cells which do not continue to divide throughout life, the size of cells varies directly with the body size and with the infrequency of division.

III. Cell Size and Nuclear Size

In a series of recent papers Richard Hertwig[12, 13] and several of his pupils have maintained that there is a definite ratio between the size of the nucleus and the size of the cell; this is the "Kernplasmarelation," or the nucleus-plasma ratio. When this ratio is altered by the greater growth of the nucleus, Hertwig thinks that it leads to a "tension," which brings about division, and thus the normal nucleus-plasma ratio is restored. This ratio is supposed to be a constant one under normal conditions, and if at any time it is altered it is capable of self regulation.

On the other hand, I[14] have found that this ratio varies greatly in different cells of an animal, and indeed within the same cell at different stages of the division cycle, that it may be experimentally altered, and that it is a result, rather than a cause, of the frequency of cell division.

Within the same cell the size of the nucleus varies greatly at different stages of the division cycle, while the volume of the cell as a whole remains relatively constant. The nucleus is smallest during the anaphase, or later stages of division, when it consists of a compact plate of condensed chromosomes; it is largest immediately before the nuclear membrane dissolves at the prophase of the next division. In the cleavage of the egg of *Crepidula plana* the nucleus-plasma ratio in identically the same cell varies from approximately 1 : 6 when the nucleus is largest, to 1 : 286 when it is smallest; that is, the volume of the nucleus increases nearly 50 times during the resting period between the previous anaphase and the subsequent prophase; during this same time the volume of the cell remains practically unchanged.

Even when measured at the same phase of the division cycle the nucleus-plasma ratio differs greatly in different cleavage cells; at maximum nuclear size the volume of the nucleus of certain cells of *Crepidula* (4*A*–4*C*) may be 3 times that of the protoplasm, whereas in other cells (1*A*–1*D*) the volume of the protoplasm may be 14.5 times that of the nucleus. At minimum nuclear size the nucleus-plasma ratio may vary from 1 : 29 in the cells $1a^2$–$1d^2$, to 1 : 285.5 in the cells 1*A*–1*D*.

The growth of the nucleus between successive divisions is due to the absorption from the cell body of a particular kind of cell substance, which constitutes the achromatin of the nucleus; at the beginning of this growth the nucleus is composed of compact chromosomes, at its

[12] Hertwig, R., "Ueber Korrelation von Zell- und Kerngrösse, etc.," *Biol. Centralb.*, 22, 1903.

[13] Hertwig, R., "Ueber neue Probleme der Zellenlehre," *Archiv Zellfors.*, 1908.

[14] Conklin, "Cell Size and Nuclear Size," *Jour. Exp. Zool.*, 12, 1912.

end it consists of a large vesicle of achromatic substance in which the chromatin usually exists as scattered granules. At the next division some of these granules form chromosomes and all the rest of the nuclear content is liberated into the cell body, to be again absorbed by the daughter nuclei during the succeeding rest period. There is thus a sort of diastole and systole of the nuclear vesicle during every division cycle of a cell, achromatin being taken up by the nucleus during its growth and liberated again into the cell body during its division.

In different cleavage cells of *Crepidula plana,* when the yolk is eliminated from consideration, the nucleus-plasma ratio varies from 1 : 0.37 to 1 : 14.5; that is, the volume of the actual protoplasm in certain cells may be only one third the volume of the nucleus, or in other cells it may be fourteen times that volume, depending largely upon the length of the resting period.

In general the size of a nucleus is directly proportional to the volume of the general protoplasm in the cell, to the length of the resting period, and in cases of abnormal or irregular distribution of chromosomes, to the number and volume of the initial chromosomes which go to form the nucleus. The inciting cause of cell division is not to be found in departures from a normal nucleus-plasma ratio, which is a result rather than a cause of the rate of cell division, but rather in the coincidence of certain metabolic phases in nucleus, centrosome and protoplasm.

If the growth period of the nucleus is very long, the greater part of the protoplasm may be taken into the nucleus, as in those cleavage cells in which the nuclear volume is about three times as great as that of the protoplasm outside of the nucleus; if the growth period of the nucleus is short, the nucleus remains correspondingly small. If nuclear division is prevented by hypertonic solutions or by decreased oxygen tension, the nuclei may grow to an enormous size until they contain the greater part of the cell protoplasm.[15]

In certain stages of the division cycle it is possible by the use of hypertonic solutions to prevent the daughter chromosomes from absorbing achromatin, and in such cases these chromosomes form small, densely chromatic nuclei, while the achromatin may be gathered into one or many vesicles. In other cases, the chromatin may be caused to contract and to squeeze out the achromatin. The latter case is similar to that which takes place normally in the formation of a spermatozoon from a spermatid, where there is a condensation of the chromatin of the spermatid nucleus and a squeezing out of the achromatin; this diminution of the nucleus is coincident with the transformation of the protoplasm of the spermatid into differentiation products. A similar thing happens in superficial epithelial cells which are undergoing keratiniza-

[15] Conklin, "Experimental Studies on Nuclear and Cell Division," *Jour. Acad. Nat. Sci. Phila.*, 15, 1912.

tion; up to a certain stage, the nuclei of such cells shrink in size and become more densely chromatic in proportion as the cell protoplasm is converted into metaplasm. The same thing is true of gland cells, muscle cells, fiber cells and fat cells in which the general protoplasm is progressively being changed into differentiation products, and coincidently the individual nuclei shrink in size and become more densely chromatic.

In no case do metaplasmic substances or differentiated structures of the cell enter into the nucleus during its growth, and the relative quantities of general protoplasm and of differentiated products in a cell can be determined by the size to which the nucleus will grow during interkinesis, under given conditions of time, temperature, etc. By subjecting eggs to centrifugal force, the quantities of protoplasm and yolk in the cleavage cells may be greatly changed, and under such circumstances the size of a nucleus is always proportional to the volume of the protoplasm in which it lies; the heavier yolk which segregates at the peripheral pole, and the lighter watery or oily substance which gathers at the central pole of the centrifuged egg do not contribute to nuclear growth, only the clear protoplasm which lies in the middle zone enters the nucleus or contributes to its growth. In muscle cells with small nuclei, the quantity of general protoplasm (sarcoplasm) which may enter into the nucleus or contribute to its growth is small; in nerve cells, it is evidently larger, since the nuclei of such cells are relatively large, but the substance which may enter the nucleus of a nerve cell is by no means as great in quantity as in germ cells and blastomeres, thus indicating that much of the substance of a nerve cell is too highly differentiated to enter into the nucleus. In epithelial and gland cells, the size of nuclei is limited not only by the presence of metabolic products in the cells, but also by the occurrence of cell division and the consequent limitation of the growing period of the nucleus.

The following table gives the cell diameter and nuclear diameter at maximum size, the corresponding nuclear volume, the cell volume less the nuclear volume, and the nucleus-cell ratio, in a number of different kinds of cells in adult individuals of *Crepidula plana:*

The nucleus-cell ratio of these cells varies from 1:1.3 to 1:88.6, depending primarily upon the quantity of formed substance in the cells. The nuclei are relatively largest in germ cells before the formation of yolk, and in embryonic cells in which there is relatively little formed substance; in such cases a relatively great part of the protoplasm may enter the nucleus. The nuclei are relatively smallest in those cells in which the protoplasm has been most completely transformed into products of metabolism or differentiation, such as gland cells filled with secretion, red blood cells of mammals in which the nuclei completely disappear, egg cells filled with yolk, and spermatozoa in which most of

the protoplasm has been transformed into the contractile substance of the flagellum.

I have not been able to measure the volume of muscle cells in *Crepidula,* but such measurements have been made by Eycleshymer[16] for the striated muscle cells of *Necturus.* From the measurements given by Eycleshymer, I have calculated the nucleus-plasma ratio in the usual manner, *i. e.,* by determining the ratio of the nuclear volume to the cell volume less the nuclear volume; and I find that in the 7 mm. and 8 mm. embryos this ratio is about 1 :11, whereas in the 23 cm. adult it is about 1 :73. The increase of cell substance is therefore less than seven times, instead of twenty or thirty times, that of the nucleus, as he states.

RATIO OF NUCLEAR VOLUME TO CELL VOLUME IN ADULT INDIVIDUALS OF *Crepidula plana*

Kinds of Cells	Maximum Diameter of Cell μ	Maximum Diameter of Nucleus μ	Volume of Nucleus Cu. μ	Volume of Cell Less Volume of Nucleus Cu. μ	Nucleus-Cell Ratio
Spermatocytes I	8	6	113	155	1: 1.37
Spermatocytes II	7	5	64.4	114.6	1: 1.7
Spermatids (chromatin condensed)	3	2	4.18	9.94	1: 2.38
Oocytes I (before yolk formation)	10	6	113	407	1: 3.6
Large ganglion cells (not including any outgrowths)	17×17×23	12	905	5724	1: 6.3
Ectodermal epithelium (of foot)	6× 6×15	5	65.4	474.6	1: 7.1
Epithelium of mantle (near anus)	5× 5×15	4	33	342	1:10.3
Intestinal epithelium	11×11×12	6	113	1339	1:11.8
Gastric epithelium	10×10×36	8	268	3332	1:12.4
Branchial epithelium	7× 7× 9	4	33	408	1:12.3
Liver cells (without secretion products)	14×14×30	9	382	5498	1:14.4
Liver cells (with secretion products)	15×15×45	6*	113	10012	1:88.6
Oocytes I (before maturation and with maximum quantity of yolk)	150	42	32409	1722591	1:53

It is important to note that Eycleshymer found that as the fibrillæ are progressively formed out of the protoplasm of the cell, the nuclei are crowded out of the center of the cell toward its periphery; that the nuclei become more densely chromatic, and especially so on the side of the nucleus toward the fibrillæ; and that possibly the nuclei may disintegrate and their chromatin go to form the dark bands of the striated

[16] Eycleshymer, "The Cytoplasmic and Nuclear Changes in the Striated Muscle Cells of *Necturus*," *Am. Jour. Anat.*, 3, 1904.

* Nucleus shrunken and irregular in shape.

muscle fiber. These facts seem to me to justify the conclusion which I reached in a former paper:[14]

> It is probable that the contractile substance which makes up the larger part of the muscle cell does not contribute to the growth of the nucleus as does the protoplasm of embryonic cells—that so far as the growth of the nucleus is concerned it acts as does yolk, oil, membranes, fibers or other products of metabolism and differentiation. If only the sarcoplasm of the muscle cell and not its contractile substance is able to contribute to the growth of the nucleus, the small volume of the nuclei as compared with the entire cell would find a ready explanation. There can be no doubt that the plasma is the chief seat of differentiation, as Minot has emphasized, and that highly differentiated cells, such as muscle, nerve, and some kinds of connective tissue, have a larger amount of plasma *and its products*, relative to the nucleus, than have embryonic cells. In the case of fiber cells, fat cells and probably muscle cells, the cell body becomes filled with the products of differentiation and metabolism, which like the yolk in egg cells, or the secretion products in liver cells can not enter the nucleus and consequently do not influence its size. In such tissue cells the cell body is relatively much greater as compared with the nucleus, than in purely protoplasmic cells, but I have been unable to find any evidence that the ratio of protoplasm (using this term in its usual sense) to the nucleus is greater in tissue cells of *Crepidula* than in the blastomeres.

Just as the size of a nucleus in any given species is proportional to the volume of the general protoplasm, so the volume of its chromosomes is proportional to the volume of the nucleus. The number of chromosomes and their relative sizes are characteristic for each species, but the absolute size of chromosomes depends upon the size of the nucleus from which they come. Throughout the period of cleavage, as the cells and nuclei grow smaller, the chromosomes also diminish in size. The view of Boveri[17] that the chromosomes divide when they have grown to their original size before division, and that thereby a definite specific size of the chromosomes is maintained, finds no confirmation in the work of Erdmann,[18, 19] Schleip[20] or myself; while the view of Koehler[21] that the autonomy of the chromosomes may be extended to their growth, which is supposed to be independent of that of other cell constituents, is flatly contradicted by the facts.

During the cleavage stages at least, neither the nuclei as a whole nor the chromosomes double in volume at each successive division as is so often assumed. The total volume of the nuclei at the 70-cell stage of *Crepidula plana* is only 2.25 times their volume at the 2-cell stage. The

[17] Boveri, Zellenstudien V., Jena, 1905.

[18] Erdmann, "Experimentelle Untersuchungen der Massenverhältnisse, etc.," *Arch. Zellforsch.*, 2, 1908.

[19] Erdmann, "Qualitative Analyse der Zellbestandteile, etc.," *Ergeb. Anat. Entw.*, 20, 1912.

[20] Schleip, "Das Verhalten des Chromatins, etc.," *Arch. Zellforsch.*, 7, 1911.

[21] Koehler, "Ueber die Abhängigkeit der Kernplasmarelation, etc.," *Arch. Zellforsch.*, 8, 1912.

volume of the protoplasm more than doubles, at the expense of the yolk, between the 1-cell and the 24-cell stages, while the total nuclear volume increases less than 1.5 times during this period. Jennings[22] has shown that the *rate* of growth is numerically greater than I had stated if one compares any stage with its immediately preceding stage, but of course this criticism does not apply to the total *actual* growth of nuclear material during any given period of development. It is often said that there is a "colossal increase of nuclear mass" but no increase in the protoplasm during the cleavage stages of the egg; and correspondingly there is said to be a great increase in the ratio of nucleus to plasma in the cleavage period. Upon this supposed increase in the nuclear material as compared with the plasma, Minot and Hertwig have based their hypotheses that the cleavage of the egg represents a period of rejuvenescence. However, in *Crepidula* and *Fulgur* among the gastropods and in *Styela* among ascidians there is no great change in the nucleus-plasma ratio during cleavage, and I believe that this will be found to be generally true for other animals. On the other hand, there is a considerable increase in the plasma at the expense of the yolk, during the cleavage period in these animals, and in this fact, rather than in an increase of nuclear substance, is to be found the cause of such rejuvenescence as may occur in these stages.

IV. Longevity, Senescence and Rejuvenescence

Apart from accidental causes of death, longevity is determined by the duration of the excess of anabolism over katabolism. If destructive metabolic changes gain ascendency over constructive ones at an early period the organism is short lived; if constructive processes are indefinitely in the ascendent the organism is potentially immortal. Such a condition is shown in *Paramecium* where Woodruff[23] has reared more than 3,000 generations without conjugation and without loss of vitality. These and other similar experiments have demonstrated the essential truth of Weismann's doctrine that Protozoa are potentially immortal. Woodruff found that the most important factors for maintaining vigor are proper food and freedom from the poisonous effects of waste products. In higher animals there is no doubt that both of these environmental factors are important, but there are also other important factors which influence length of life which are not entirely environmental.

Duration of assimilation conditions not merely body size, but also length of life. Very large animals are long lived and small ones are

[22] Jennings, "Nuclear Growth during Early Development," *Am. Nat.*, 46, 1912.

[23] Woodruff, "Dreitausend und dreihundert Generationen von Paramecium, etc.," *Biol. Centralb.*, 33, 1913.

apt to be short lived, though the latter is by no means universally true —length of life being conditioned by *duration* of the ascendency of assimilation over dissimilation, whereas size is conditioned also by *rate* of assimilation as contrasted with dissimilation.

Weismann has pointed out a relation between longevity and the rate of reproduction—animals in which there is a slow rate of reproduction being in general long lived, while those in which the rate of reproduction is rapid are generally short lived. Numerous exceptions to this rule may be cited, though in many cases it is undoubtedly true; but Weismann has not proved that length of life is the result of slow reproduction. It may well be that both length of life and rate of reproduction are dependent upon the duration and rate of assimilation and dissimilation in somatic and germinal cells.

There is also an undoubted relation between longevity and adaptability, or the power of regulation. If life is continuous adjustment of internal conditions to external conditions, length of life may be said to depend upon the duration and perfection of such adjustment. The power of regulation is much less perfect in some animals than in others, and at certain stages of the life cycle than at other stages. But in all animals this power is greatest where the relative proportion of protoplasm to metaplasm, or differentiation products, is greatest, and where the protoplasm is most labile. In Protozoa this power of regulation is shown at every division and it suffers no abatement in successive generations; in Metazoa generally the power of regulation is greatest in early stages of development and in tissues in which protoplasm is abundant, and it diminishes as life advances and as the products of differentiation more and more replace the protoplasm. In the fission of a *Paramecium* there is a certain amount of dedifferentiation preceding division and of redifferentiation succeeding it, and as a result of this the two halves of the original *Paramecium* become alike; furthermore, in successive generations, there is no accumulation of the products of differentiation. In the division of the eggs of Metazoa the cleavage cells sooner or later become unlike, owing to the differentiations present in the mother cell and the failure of complete regulation in the daughter cells. This progressive differentiation is accompanied by a progressive loss of the power of regulation, and when the general protoplasm is so completely transformed into differentiation products that the power of regulation is completely lost, the organism as a whole must lose the power of adjustment to external conditions, and hence of indefinitely continued life.

Many different hypotheses have been advanced to account for the running down of the vital machine. That death is not a necessary corollary of life is evidenced by the potential immortality of Protozoa and of the germ cells of Metazoa. Senescence, like all other processes

occurring in organisms, is primarily a cellular phenomenon. The decline and degeneration of cells begins in the earliest stages of individual development; in many cases large numbers of germ cells regularly undergo degeneration, apparently as the result of intrinsic rather than of extrinsic causes. The polar bodies which are formed during the maturation of the egg are at the same time the smallest and the shortest lived cells in the entire life cycle; they rarely last beyond the cleavage period and do not grow at all. Evidently their degeneration is due to lack of the power of assimilation, rather than to the accumulation of waste products, or to the increase of formed material. This lack of the power of constructive metabolism is evidently not due to lack of chromatin, for at the time of their formation they contain as much chromatin as the egg cell itself; they usually contain very little protoplasm, but even when the quantity of protoplasm in them is very greatly increased, through the effects of pressure or centrifugal force at the time of their formation, they still lack the power of assimilation and differentiation. Such a large polar body resembles an unfertilized egg, and like it is incapable of development unless stimulated by the entrance of a spermatozoon or by some artificial means.

In many cases certain cleavage cells run through their development quickly and then degenerate and disappear, while other neighboring cells live as long as the organism itself. Many larval or fetal organs have a very short life; the cells of which they are composed grow and divide rapidly for a time and then dissimilation exceeds assimilation and they dwindle and disappear. Throughout the mature life of any metazoan many cells are continually growing old and dying, while others take their places. Even in the oldest organisms certain types of cells are still young enough to grow and divide, and there is no reason to doubt that such cells are potentially immortal and, if saved from the general death of the organism by isolation, might live indefinitely. Cells which continue to grow and divide throughout life apparently never grow old. It is customary to speak of the germ plasm as potentially immortal, but it is not generally recognized that other kinds of plasm may also be immortal. Indeed all kinds of protoplasm may be regarded as potentially immortal, except when processes of constructive metabolism are prevented in one way or another. In most cases the power of cell division is lost before that of growth, and the presence or absence of cell division is therefore indicative of youthful or of senile conditions in the cells concerned. Measured by this standard, certain cells grow old at a very early stage in the life cycle, whereas others remain young until overwhelmed by the general death of the organism. Senescence then is not a uniform process for the entire organism; it begins in certain cells at a very early stage of development, while it may not appear at all in other cells.

The possible causes of senescence and rejuvenescence may be classified as structural and functional, though these two should not be regarded as mutually exclusive. Indeed it is practically certain that both structure and function are involved in these processes as in most other vital phenomena. However, different students of this subject have placed emphasis more or less exclusively upon either the structural or the functional causes of senescence and rejuvenescence.

Under the structural causes may be cited Minot's hypothesis that senescence is caused by an increase in the amount of protoplasm as compared with the nucleus. In 1890 he[24] summarized his views on this subject in the following words:

> We have then to state, as the general result of the studies which we have just made, that the most characteristic peculiarity of advancing age, of increasing development, is the growth of protoplasm; the possession of a large relative quantity of protoplasm is a sign of age. . . . We see that there is a certain antithesis, we might almost say a struggle for supremacy, between the nucleus and protoplasm.

In several subsequent papers and books,[25] Minot has developed this idea at length. In his book on "Age, Growth and Death,"[26] he concludes that

> Rejuvenescence depends on the increase of the nuclei, senescence depends on the increase of the protoplasm and on the differentiation of the cells.

R. Hertwig's[28] views are apparently diametrically opposed to those of Minot. He finds that senescence or rather "depression" and "physiological degeneration," in *Actinospherium* and Infusoria are accompanied by an enormous growth of the nucleus. He regards the immature egg cell with its great nucleus as in a condition of depression similar to that found in the protozoa named. By the processes of maturation and fertilization this nuclear material is greatly reduced and thus the cells are brought back to a normal condition.

As opposed to the hypotheses of Minot and Hertwig, it may be pointed out that the larger part of a resting nucleus is composed of achromatin which has been absorbed from the cell body, and that the size of a nucleus depends chiefly upon the quantity of general protoplasm in a cell and upon the length of the resting period during which the nucleus is absorbing this protoplasm. So far from there being an antithesis between nucleus and general protoplasm, we find that the general protoplasm is common to both; small nuclei occur only in cells

[24] Minot, "On Certain Phenomena of Growing Old," *Proc. Am. Ass'n Adv. Sci.*, 29, 1890.

[25] Minot, "Ueber Vererbung und Verjüngung," *Biol. Centralb.*, 15, 1895.

[26] Minot, "Age, Growth and Death," Putnams, New York, 1908.

[28] Hertwig, R., "Ueber die Kernkonjugation der Infusorien," *Abh. Bayer. Akad. Wiss.*, II. Kl., 17, 1889.

with a small amount of such protoplasm, while large nuclei occur only in cells with a large amount. It is not the increase in the general protoplasm which causes the nuclei to become relatively small, but rather the increase in the differentiation products and the corresponding decrease in the general protoplasm.

In most respects I am in hearty accord with Minot's latest formulation of the causes of senescence.[27] In this work he particularly emphasizes the effect of differentiation in causing senescence. Indeed he concludes, "dass die Differenzierung als die wesentliche Ursache des Altwerdens zu betrachten ist." Nevertheless, he still holds that the greater growth of the protoplasm, relative to the nucleus, is the essential basis of differentiation; and that we may distinguish in development an earlier and shorter period, which is characterized by the preponderating growth of the nucleus, from a second and longer one characterized by growth and differentiation of the protoplasm—the former being the period of rejuvenescence, the latter the period of senescence. In *Crepidula,* as I have shown,[14] the growth of nuclear material during early cleavage is not greater than that of the protoplasm, and in general the size of a nucleus is directly proportional to the quantity of general protoplasm and to the length of the resting period, because general protoplasm is absorbed by the nucleus during interkinesis, whereas products of differentiation do not enter the nucleus. A causal explanation is thus given of the relation between nuclear size and cell size at different stages of development; and in the fact that differentiation products can not enter the nucleus we have, I believe, a causal explanation of the relation between differentiation and senescence.

The principal objection to Minot's formulation of the cause of senescence is that it overemphasizes the antithesis between nucleus and protoplasm and does not with sufficient clearness distinguish between the general protoplasm and its differentiation products. It is undoubtedly true that with advancing age and differentiation there is an increase of cellular as compared with nuclear substance, but the significant thing here is the fact that this cellular increase is not so much in the protoplasm as in the products which are formed from it and which can not enter into the nucleus.

By all odds the most important structural peculiarity of senescence is the increase of metaplasm or differentiation products at the expense of the general protoplasm. This change of general protoplasm into products of differentiation and of metabolism is an essential feature of embryonic differentiation and it continues in many types of cells until the entire cell is almost filled with such products. Since nuclei depend upon the general protoplasm for their growth, they also become small in such cells. If this process of the transformation of protoplasm into

[27] Minot, "Moderne Probleme der Biologie," Fischer, Jena, 1913.

differentiation products continues long enough it necessarily leads to the death of the cell, since the continued life of the cell depends upon the interaction between the general protoplasm and the nucleus. In cells laden with the products of differentiation, the power of regulation is first lost, then the power of division, and finally the power of assimilation; and this is normally followed by the senescence and death of the cells.

In some cases the progressive transformation of protoplasm into metaplasm may be reversed; in some manner the formed material is dissolved and converted into general protoplasm, the protoplasm and nuclei increase in size, the cells begin to divide and may become capable of regulation. In short, this reversal of the differentiation process leads to the rejuvenescence of senile cells. Minot[27] holds that differentiated cells do not become undifferentiated—but at least it must be admitted they may lose their products of differentiation and metabolism; gland cells lose their secretion granules, egg cells their yolk, spermatozoa within the egg their flagella, injured muscle cells their fibrillæ, etc. In such cases differentiation products are either eliminated from the cell or are transformed into a more labile and more general form of protoplasm, though the latter is probably not undifferentiated. I have used the term *dedifferentiation* for this process.

Among functional causes of senescence may be mentioned the well-known opinion of Metschnikoff, that the organism is slowly poisoned by its own waste products. Metschnikoff especially emphasizes the effects of intestinal fermentation and putrefaction in producing old age. Zoologists are familiar with the fact that, in certain Polyzoa and Tunicata which lack kidneys or efficient means of eliminating urea, or other nitrogenous waste, the tissues gradually become laden with such waste substances and the animal becomes senile and finally dies, but before this happens it may give off one or more buds which are relatively free from these waste products and which continue the life of the colony. It is a general phenomenon both in plants and animals that buds are composed of protoplasm which is not laden with products of differentiation or metabolism, and hence they exhibit youthful characteristics although the body from which they come may be senile.

Another functional cause of senescence is to be found in a decrease in the power of constructive metabolism. This factor has been recently advocated by Child[29] in a very valuable paper, in which he concludes that anything which decreases the rate of metabolism, such as "decrease in permeability, increase in density, accumulation of relatively inactive substances, etc.," will lead to senescence. On the other hand, "Rejuvenescence consists physiologically in an increase in the rate of

[29] Child, "A Study of Senescence and Rejuvenescence, etc.," *Arch. Entw. Mech.*, 31, 1911.

metabolism and is brought about in nature by the removal in one way or another of structural obstacles to metabolism."

It is well known that constructive metabolism can not take place in the absence of a nucleus, and I have elsewhere[14] shown that the interchange between the nucleus and the protoplasm is a condition of assimilation. I have likewise shown that only the general protoplasm can enter the nucleus and that the products of differentiation are excluded from it. The progressive increase of such products and corresponding decrease in the general protoplasm lessen this interchange between nucleus and cell body and thus decrease the power of constructive metabolism.

In conclusion it may be said that there are several factors which produce senescence, but that the chief of these is the progressive differentiation of the protoplasm. As Minot has well said "Old age and death are the price which we pay for our differentiation." If we could find means by which this progressive differentiation could be stopped or reversed when it has gone too far, we might hope to attain potential immortality. That the possibility of this is not a mere delusion is shown by the fact that there are many animals which either in whole or in part are capable of rejuvenescence. In Protozoa the dedifferentiation which usually precedes or accompanies division is a process of rejuvenescence, and where such dedifferentiation and division are long delayed even protozoans show signs of old age. The same is true of germ cells; the mature egg and sperm are senile cells not because the one has a very large nucleus and the other a very small one, but because both are loaded with products of differentiation which interfere with constructive metabolism. When the sperm enters the egg and either leaves behind its old cell body or dissolves it, and its nucleus gets a new protoplasmic body, it is rejuvenated; likewise when the egg begins to dissolve the yolk and other products of differentiation with which it has been loaded it begins to live anew.

Similarly any adult animal or plant which is capable of dedifferentiation is also capable of renewing its youth. It has long been known that encystment and accompanying loss of differentiation lead to rejuvenescence. Jacobs,[30] working under my direction, found that when the rotifer, *Philodina,* becomes senescent, it may be rejuvenated if it is completely dried up and afterwards put back into water; in this treatment it evidently undergoes dedifferentiation.

Child[29] found that after planarians in a condition of apparent extreme senility had been starved for some time, they afterward became young within a few hours or days. Evidently the starving served to use up a part of the structural substance which prevented rapid metabolism.

[30] Jacobs, "The Effects of Desiccation on the Rotifer *Philodina roseola*, *Jour. Exp. Zool.*, 6, 1909.

Similar conditions of renewed vigor are shown by many animals after long hibernation. The great breeding activity of many animals, such as frogs, so soon after their winter sleep, may find a physiological explanation in this using up of metabolic products during hibernation and the subsequent increase in vitality.

In similar manner it is known that the new tissue which is formed in regeneration comes from undifferentiated (epithelial or lymphoid) or from dedifferentiated cells (*e. g.*, muscle cells of amphibia, etc.). In the latter case also there is a rejuvenescence, due to the loss of differentiation products. In this case dedifferentiation is evidently due, in the first instance, to the injury. It is at least possible that the failure to regenerate lost parts, which many animals show, is due to the inability of the cells to undergo dedifferentiation and subsequent rejuvenation.

In conclusion, we find that the life of a cell is dependent upon the continued interaction of nucleus and protoplasm; that as the protoplasm is transformed into products of differentiation this interaction of nucleus and protoplasm is reduced and constructive metabolism is diminished; that when the quantity of protoplasm present has been reduced beyond a certain point, either by its transformation into metaplasm, or by other means, constructive processes fail to compensate for destructive ones, and the cell grows old and finally dies. On the other hand, processes which lead to the increase of the general protoplasm in a cell, either by the growth of the protoplasm already present or by the conversion of metaplasm into protoplasm, lead also to the growth of the nucleus, to increased interchange between nucleus and protoplasm, and hence to increased powers of assimilation, cell division and regulation. Anything which decreases the interchange between nucleus and protoplasm leads to senility; anything which decreases this interchange renews youth. increases(?)

BERNOULLI'S PRINCIPLE AND ITS APPLICATION TO EXPLAIN THE CURVING OF A BASEBALL

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WHEN a liquid or a gas is flowing through a horizontal pipe and encounters a constriction in the pipe, there is a higher velocity of the fluid and a lower pressure in the constriction than in the larger section of the pipe. At first thought, this is contrary to what one would expect, for the crowding of the fluid into a smaller section would apparently raise the pressure. Closer analysis, however, shows that places in the pipe where the velocity of the fluid is greater must be places of lower pressure and at places where the velocity of the fluid is less, the pressure must be greater.

Consider a definite mass of water as m in Fig. 1. When this piece of water moves from position A to position B, its velocity is increased

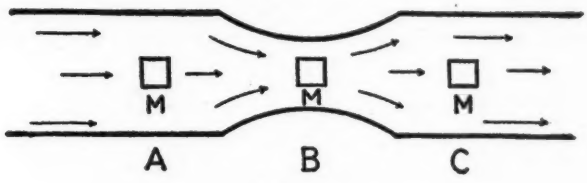


FIG. 1.

since the velocity of the water in the smaller section of the pipe must be larger than in the larger section if the same amount of water per second which flows through the larger section is to go through the smaller section. Since the velocity of this mass of water is increased (mass m is accelerated) there must be an unbalanced force acting on it. This unbalanced force is furnished by a higher pressure at position A than at position B. That is, the pressure behind the moving mass m is greater than in front of it and, consequently, the velocity is increased. As the piece of water leaves the neck in the pipe, the pressure in front of it is greater than the pressure behind it and it slows down to the lower velocity in the larger section of the pipe.

The generalization of the above described phenomenon is, that places in a fluid where the velocity is relatively greater are places of lower pressure and places where the velocity of the fluid is relatively

smaller are places of higher pressure.[1] This generalization (first established by John Bernoulli) is called Bernoulli's principle and its application to explain many paradoxical results is interesting.

Fig. 2 shows how the weight of a marble may be held up by blowing through the tube. The high velocity of the air over the top of the marble causes a lower pressure than there is under the marble where the air has a comparatively low velocity and this difference in pressure exerts an upward force which is sufficient to balance the weight of the marble.

A light ball may be held in midair by a stream of air flowing just above it, as shown in Fig. 3. Just above the ball is a region of high

FIG. 2.

FIG. 3.

velocity and low pressure, while under the ball is a low velocity and high pressure region and therefore the force of gravity on the ball is balanced by the difference in pressure.

The difference between the higher pressure in the larger section and the lower pressure (higher velocity of water) in the smaller section of a water pipe is indicated by the manometer in Fig. 4. The pressure in the larger section of the pipe is greater than the pressure in the smaller section by an amount equal to the pressure exerted by a column of mercury h high. If the areas of the larger and smaller sections are known, the rate at which the water is flowing through the pipe (cubic feet per second or gallons per second) can be determined from the difference in pressure which is indicated by the manometer. This method of measuring rates of discharge is used in the Venturi water meter, which is not essentially different from the arrangement shown in Fig. 4.

[1] When a fluid flows from a region of low velocity to a region of high velocity the pressure decreases but the reverse, that when a fluid flows from a region of high velocity to a region of low velocity the pressure increases, is not always true. For example, the friction of the water against the sides of the tube in Fig. 1 might be sufficient to decrease the velocity of the water as it flows out of the neck without the pressure increasing.

A baseball moving through the air is the same as air moving past the baseball as far as the forces which the air exert on the ball are concerned. A ball thrown straight (without rotating) through the air can

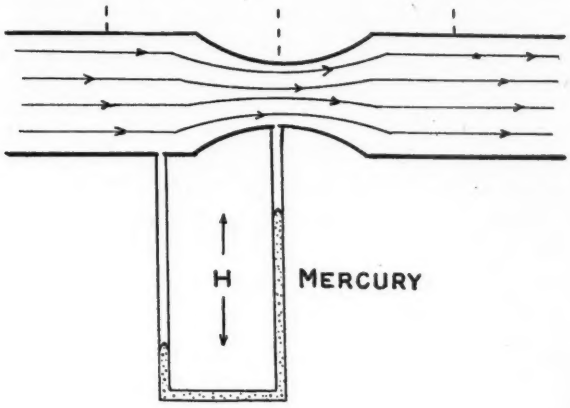


FIG. 4.

be pictured as air moving past the ball with the same velocity on all sides of the ball which is shown by the equal density of stream lines above and below the ball in Fig. 5. According to Bernoulli's principle,

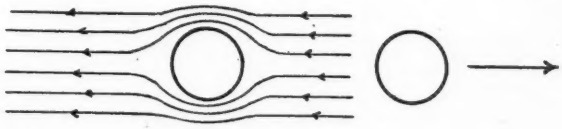


FIG. 5.

there are equal pressures (equal velocities) of the air on all sides of the ball and it does not curve.

If the ball is rotating as it moves through the air, its spin will increase the velocity of the air past the ball on one side and retard the velocity of the air past the ball on the opposite side as is indicated in Fig. 6 by many stream lines on one side and few on the other. The higher pressure (low velocity) on the one side pushes the ball toward the low pressure (high velocity) region and it curves as shown by the heavy arrow in Fig. 6. If the ball had been rotating in an opposite

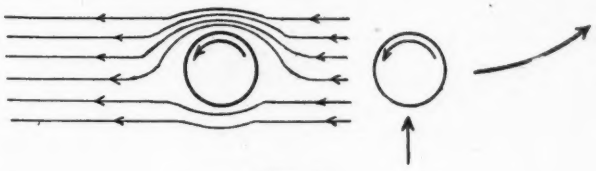


FIG. 6.

direction, the low pressure region would have been on the other side of the ball and it would have curved in the opposite direction.

In order to show this difference in pressure on the sides of a rotating ball as it is thrown through the air, or in practise as the air is driven past the ball, the author has devised the following demonstration. The air is driven past the ball by a centrifugal blower and the pressures on two opposite sides of the ball are indicated by manometers as shown in Fig. 7.

When the ball is not rotating, the velocity of the air on the two sides of the ball is the same (shown by equal density of stream lines in top view section of Fig. 8) and the manometers indicate equal pressures on the two sides of the ball (end view of Fig. 8). This is equivalent to the ball going through the air without rotating and without curving to either side as shown by the heavy arrow. However, the pressure on either side of the ball is less than the pressure in the still air outside the tube which directs the air past the ball; that is, the high velocity regions near the ball are low-pressure regions.

When the ball is rotating as shown in Fig. 9 the friction against the surface of the ball accelerates the flow of air past it on one side and retards the air stream on the other side; that is, the stream lines are more dense on one side (shown in top view of Fig. 9) and the manometers indicate unequal pressures on the two sides of the ball (shown

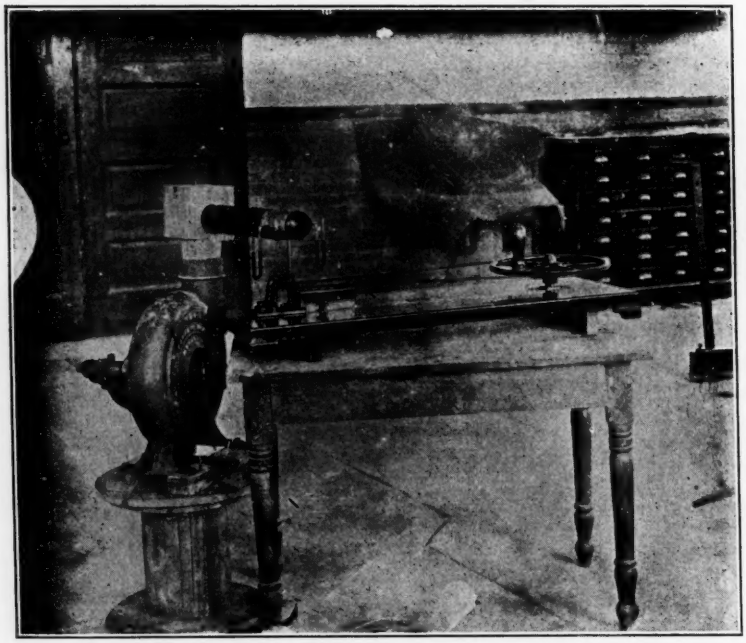


FIG. 7.

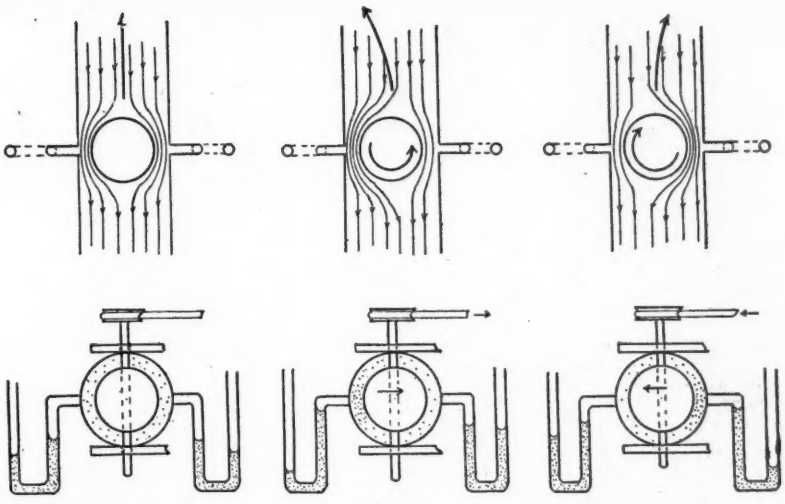


FIG. 8. FIG. 9. FIG. 10.

in end view of Fig. 9). This is equivalent to the ball going through the air with a rotary motion and the difference in pressure on the two sides curves it as shown by the heavy arrow.

If the rotation of the ball is reversed, the lower-pressure region (higher velocity region) is on the other side of the ball. This is equivalent to the ball going through the air with a rotary motion as shown in Fig. 10 and the difference in pressure on the two sides of it causes it to curve as shown by the heavy arrow.

MAIN BUILDING OF THE BUREAU OF SCIENCE AT MANILA

THE PROGRESS OF SCIENCE

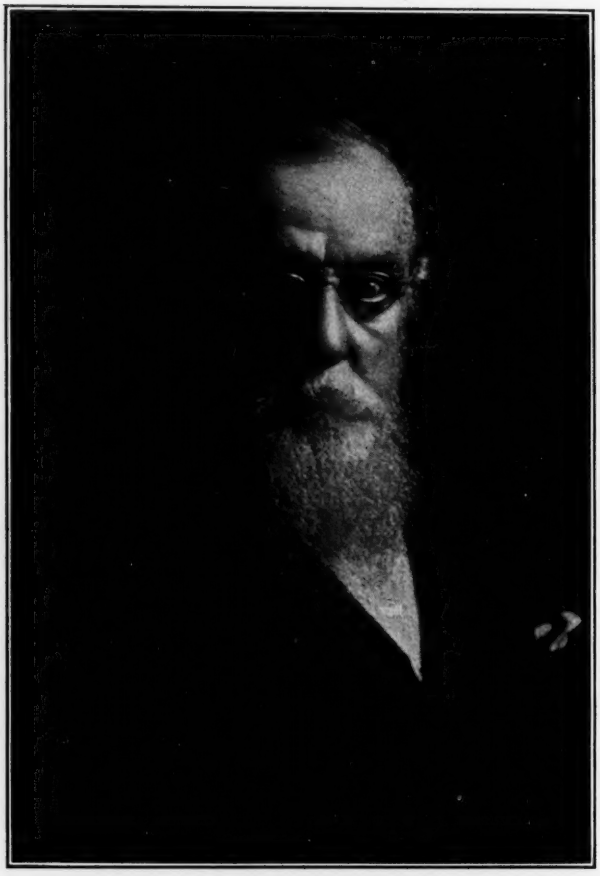
THE BUREAU OF SCIENCE OF THE PHILIPPINE ISLANDS

THE annual report of the acting director of the Bureau of Science, maintained under the government of the Philippine Islands, for the year ending with July, 1912, has just reached this country, and bears witness to the accomplishment of a considerable amount of scientific work. It might be better if the native peoples were permitted to follow their natural lines of development, but scientific investigation and the common schools are probably better for them than the rule of the Spanish friars. In any case, the serious efforts made by the Bureau of Science to investigate the natural history and natural resources of the islands and the tropical diseases that occur there will be of value to the world at large. Government and investigations in a tropical country, however, can be carried forward only at a heavy cost, and we should probably adopt the English policy of paying large salaries and permitting early retirement on a pension.

The present report gives evidence of the difficulty of maintaining a scientific staff. Dr. Paul C. Freer, director of the Bureau of Science from the time of its organization as the Bureau of Government Laboratories in the year 1901, dean of the college of medicine, and professor of chemistry in the University of the Philippines, died last year. The important work that he accomplished in advancing science and education was thus paid for at a heavy price. Several others of the most active workers in the bureau have returned to the United States, and just now Dr. Richard P. Strong, chief of the biological laboratory, has accepted a chair of tropical medicine in the Harvard Medical School.

During the year a new wing was added to the laboratory building, as shown in the foreground of the accompanying illustration. The division of mines, the sections of fisheries and ornithology, the entomological section and laboratories and the library were moved into it. The room in the main building vacated by the library now contains the herbarium, and other rooms left vacant by the readjustments are occupied by laboratories and for clerical work.

The amount of research work accomplished by the bureau is born witness to by *The Philippine Journal of Science*, established by Dr. Freer. It is published in four sections—one devoted to the chemical and geological sciences and to the industries, one to tropical medicine, one to botany and one to general biology, ethnology and anthropology. During the year under review, there were published in these sections of the journal about one hundred articles, most of them by members of the staff of the Bureau of Science. Among the work published or to be published in the *Journal* may be noted the proceedings of the International Plague Conference at Mukden in 1911, of which Dr. Strong and Dr. Teague were members. Experiments have been carried on in several directions, including work on beri-beri, surra and entamœbic dysentery. In the botanical section additions have been made to the herbarium which now numbers over 100,000 specimens, but apparently no very great amount of field work has been done. The division of entomology has done economic work in promoting silk culture and has carried on campaigns to exterminate the mosquito and other disease-bearing insects. The section of fisheries has studied shells used in the manufacture of buttons, tortoise shells, the shark-fin industry and the manufacture of leather from the skins of marine animals. Something, but apparently not much, has been accomplished in stocking the streams with game fish and in the



SIR JONATHAN HUTCHINSON,
the distinguished London surgeon and author who has died at the age of eighty-five years.

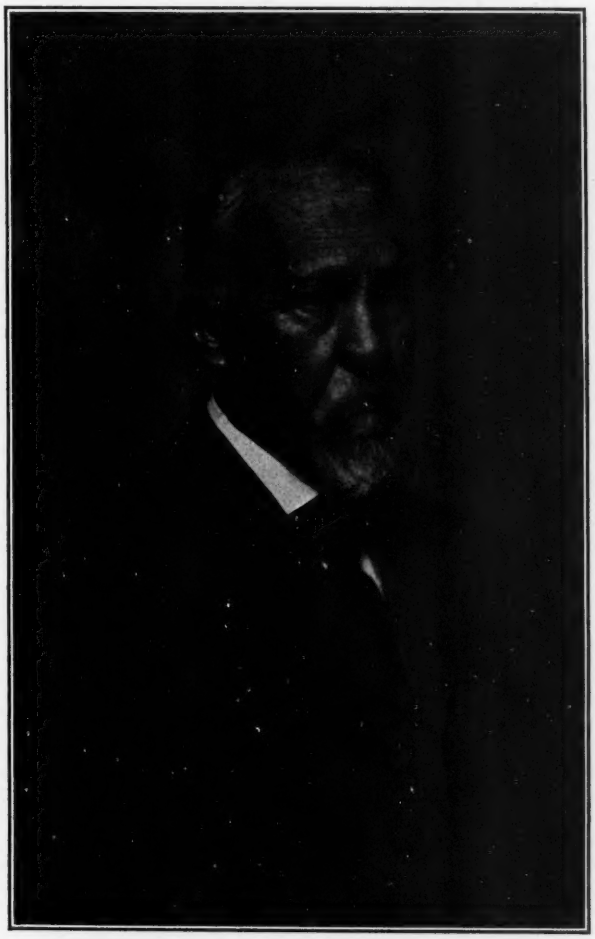
study of the deep-sea fisheries. An aquarium has been built in the bastion in front of the Real Gate of the city. The chemical laboratory like the biological laboratory is largely occupied with routine work, there having been made last year over 10,000 analyses and tests. The investigations include the study of Philippine soils, coal and Portland cement. A sugar laboratory has been opened at Iloilo, and it is recommended that there be established an experiment station in that region, where sugar cane of various kinds can be tested. The division of mines has, like the other departments, been largely occupied with routine work. Investigations have been made of the black sands, of the ore deposits, including gold veins, and of the raw materials for cement. The division of ethnology has continued the study of the Ilоco people and the museum has been developed.

It is three years since the bureau has had an increase in appropriations in spite of the fact that demands upon it have increased in every direction. The need is urged of a new testing laboratory, of enlarging the soil surveys, of the study of animal diseases and of insects injurious to agricultural products, of enlarging the library and of developing the scope of the work on the fish and fisheries of the islands.

DISTRIBUTION AND CAUSE OF PELLAGRA

DR. LOUIS W. SAMBON, of the London School of Tropical Medicine, who is about to visit the United States in response to an invitation to join the Pellagra Commission which is working in South Carolina, contributes to the last number of *The British Medical Journal* an article giving an account of several cases in Great Britain and of his theory of the natural history of the disease. Pellagra has been recognized for two centuries, but until recently was supposed to be confined to the peasantry in parts of Italy and other regions adjacent to the Mediterranean. The symptoms are first a red smarting rash—whence the name of the disease—headache, giddiness and diarrhœa. It appears in the spring, declining towards autumn, and is likely to recur with increased intensity the following spring. Death frequently follows, or a complete disorganization of the nervous system, leading to imbecility and a mummified condition of body.

The theory of Lombroso that pellagra is caused by eating moldy maize was widely accepted, until Dr. Sambon at a meeting of the British Association



PROFESSOR WILLIAM MORRIS FONTAINE,
for thirty-one years professor of natural history and geology in the University of Virginia, who has died at the age of seventy-eight years.

in 1905 suggested that it was probably of protozoal origin, and was communicated by sand flies, as sleeping-sickness is by the tsetse fly or malaria and yellow fever by mosquitoes. Since that time Dr. Sambon has made careful studies in Italy and elsewhere, and his views are accepted by a number of leading authorities. He calls attention to the analogy with malaria, especially in its seasonal occurrence. While Dr. Sambon has been able to produce no experimental evidence of the causes of the disease, Dr. W. H. Harris, of Tulane University, has recently published in *The Journal* of the American Medical Association a note on experimental production of pellagra in monkeys. These monkeys were injected with filtrates, made through a Berkefeld filter, obtained from cases of pellagra shortly after death, and all showed the typical symptoms of the disease.

As recently as 1906 Sir William Osler in the sixth edition of his "Principles of Medicine" stated that the disease has not been observed in the United States. In the following year, Dr. G. H. Searcy in Alabama and Dr. J. W. Babcock and J. J. Watson in South Carolina recognized the disease. Their reports were received with skepticism and even with ridicule, but now pellagra is known to exist in no fewer than thirty-three states and there are probably at present 30,000 cases. It is strange that pellagra and the hookworm disease, both of which are so prevalent and so disastrous in our southern states, should have remained until recently unrecognized. Both diseases are preventable, and we may look forward to a great advance in health and social efficiency when they have been brought under control in the south. We should be grateful to the General Education Board for the work that it has accomplished in this direction, but the national government, the states and the municipalities should now take up the suppression of preventable diseases with all the resources at their command.

SCIENTIFIC ITEMS

WE record with regret the death of Dr Horace Jayne, formerly professor of vertebrate morphology in the University of Pennsylvania; of Professor N. H. Alcock, professor of physiology in McGill University, and of Dr. Philip Lutley Sclater, from 1859 to 1902 secretary to the Zoological Society of London, distinguished for his work on systematic zoology.

DR. JOSEPH SWAIN, president of Swarthmore College, has been elected president of the National Educational Association; Dean Gardner C. Anthony, of Tufts College, president of the Society for the Promotion of Engineering Education, and Dean Victor C. Vaughan, of the University of Michigan, president of the American Medical Association.

IN the article on "Ancient Man, his Environment and his Art," which appeared in the July number of THE POPULAR SCIENCE MONTHLY, Fig. 4 is from a photograph by Professor V. Commont, and Figs. 7–10 are from photographs by Count Bégouen.

THE editor has received a letter from Professor Karl Pearson, the Francis Galton Eugenics Laboratory, University of London, under date of June 9, in which he says:

The following paragraph occurs in your June issue in a paper by Professor H. E. Jordan: "We are now in possession of facts, thanks mainly to the labors of Professor Karl Pearson and his collaborators at the Galton Eugenics Laboratory, and to Professor Davenport and his staff of assistants at the Eugenics Record Office, showing that the inheritance of several scores of human physical and mental traits are in close conformity with Mendelian formulæ" (p. 580). Such a statement will astonish those who are acquainted with the work done here, and I feel bound at once to state that, as far as my experience reaches, I find no physical or mental trait with which we have dealt here to be "in close accordance with Mendelian formulæ." The almost amusing aspect of the matter is, that the one paper in which I have dealt with the mulatto was an endeavor to show that Mendelian formulæ did not hold for him.